STABILITY ANALYSIS OF DUMP WITH ADMIXTURE OF FLY-ASH AND OVERBURDEN MATERIAL IN OPEN-CAST COAL MINES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

TAPAN NAYAK

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DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA – 769 008

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CERTIFICATE

This is to certify that the thesis entitled, ***"STABILITY ANALYSIS OF DUMP WITH ADMIXTURE OF FLY-ASH AND OVERBURDEN MATERIAL IN OPEN-CAST COAL MINES"*** submitted by Sri **Tapan Nayak, 110MN0596** in partial fulfilment for the award of Bachelor of Technology in Mining Engineering at National Institute of Technology Rourkela, is a record of original research work carried out under my supervision. The contents of this thesis have not been submitted elsewhere for the award of any degree what so ever to the best of our knowledge.

Dr Singam Jayanthu
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Date:

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ABSTRTACT

Dump slopes with admixture of Fly-ash and overburden material for geo-mining conditions of mine A and mine B are simulated in FLAC SLOPE and OASYS software. Stability analysis of dump slope for mine B was carried out by field monitoring using total station and monitoring stations.

For mine A, with addition of 15% fly-ash for a 30 m bench, the safe bench angle decreased by 2^0. This may be attributed to partial filling of the voids. With addition of 30% fly-ash, the safe bench angle increased by 1^0, which may be attributed to filling of void spaces. For the simulated conditions of 3 decks each of 30 m height, 28^0 angle and 40 m width of bench in mine B, the Factor of Safety (FOS) indicated through FLAC SLOPE for material with OB+25% fly-ash and layer wise dump construction are respectively 2.81 and 2.06. The difference may be because of reduction in unit weight in the former case. From the field monitoring data of Mine B dump, it is observed that the dump formed as admixture of fly ash and overburden material is stable.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Mine dump yards safety are the most neglected part in mining companies. Recently when many accidents took place because of sliding of the dumps, a more strategic and planned action has been adopted by many mining companies to ensure the stability of the dumps. One of the recent approach adopted is mixing the overburden with fly-ash. Using of fly-ash in dump stabilisation serves basically two purposes. First it stabilizes the dump and second it helps in reducing the pollution because of fly-ash. In this direction MoEF has also issued notification that mines can use fly-ash from power stations, if it lies within 50 km radius of the mine.

Before dumping the waste material, the first thing we need to do is to simulate the in-situ condition of the dumps in a software. This will help us to optimize cost, stability and floor area. For this we need numerical modelling software. The numerical modelling software used here is FLAC SLOPE and OASYS. The reason for selecting FLAC SLOPE is that, it is easy to learn, use and most widely accepted software in mining industry. OASYS is selected because this software is specifically mend for dump materials (like soils) and circular failure can be very accurately analysed in this software. In this present study, geo-mining details from KTK mine (mine A) and JPL mine (mine B) are simulated in the two software mentioned above.

After dumping the material we need to carry out on-field stability monitoring of the dumps. Any future accident and possible catastrophic failure of the dumps can be avoided by following this step. It is a must step and should be carried out in specific intervals, to know the movements in the dump. Some of the mining companies are showing interest in this and are investing a valuable fund to implement recent technology for dump slope monitoring. Such an initiative was carried out by mine B, whose details are studied in this report.

1.1 OBJECTIVES OF THE PROJECT

Stability analysis of Dump with admixture of Fly-ash and Overburden material, using Numerical modelling (FLAC SLOPE and OASYS) and Field monitoring technique, in open-cast coal mines.

1.2 METHODOLOGY OF THE PROJECT

The project methodology is described below in a flow-chart:

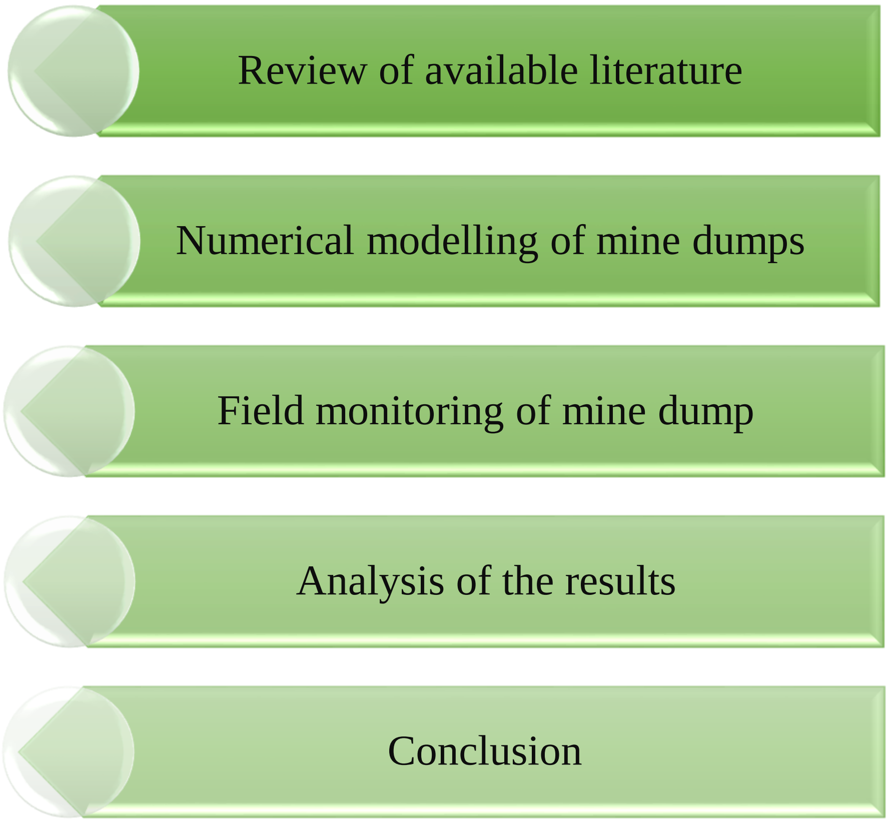

Figure 1.1: Flow-sheet of the project methodology

CHAPTER 2

LITERATURE REVIEW

2.1 OPEN-PIT DUMP TYPES

There are basically 3 types of dumps. They are:-

1) **External dumps:** External dumps means wastes dumped outside the excavation. It is suitable for thick and moderately dipping to steep seams. Mostly in hilly terrains external dumps is preferred.

   Areas less suitable for agriculture like pits depressions, mullas, jores, and in some cases marshes and lakes may be utilized for external dumping, without dislocating the natural drainage. Further external dumping is divided into: - Horizon-wise dumps and group/ bench wise dumps.

2) **Internal dumps:** Internal dumps, as the name suggests, wastes' dumped inside the excavation. It is suitable for horizontal deposits having dip of $5^0 – 12^0$. In coal mines 40% of the overburden must be dumped within the pit, even during mining.

3) **Mixed dumps:** Combination of the above two dump types.

For external dumps location of dump sites mainly depends on the following factors:

- Pit location and size through life.
- Access route for material transport.
- Area topography and mine boundary.
- Waste rock volume and type.
- Existing drainage routes.
- Material handling equipment's.
- Reclamation needs of the dumps and the mine.
- Complete safety to equipment's and workers during dump formation.

- Maximum haulage cost, so dumps should be as close to the mine site as possible.

2.2 DUMP DESIGN

Our main aim of designing dumps is to see that the dump site undergoes Maximum horizontal and vertical movement with respect to the source where it is generated. Survey shows that 25-30% of mine waste embankments in Canada had slope stability problems. Soil dumps of height over 30 metre in interior coal province of U.S.A had some type of slope stability problems. With increasing dump height, the following safety measures need to be considered:-

- Boundaries of the slide area.
- Slope angle and configuration of slide.
- Vertical down set at the head of slide.
- Pre-slide indications.
- Precipitation preceding the slide.
- Any blockage of drainage, blockage or release of seepage.
- Survey profile of slide area.

2.2.1 Factors Influencing Dump Stability:

- **Grain size:** The size and shape of individual particles is of much importance in slope design because this will determine the porosity, permeability, unit weight etc. More is the grain size more will be the porosity and this will enhance increase seepage of water through the dump material. Hence the factor of safety will reduce. To decrease the porosity we add Fly-ash, and through modelling I will show that FOS practically increases with addition of fly-ash.

- **Dump slope angle and over-all slope angle**: This is one of the most important factor in deciding slope stability. Keeping the bench width and height constant, if we increase the bench angle (& so the overall slope angle), the FOS decreases. The overall slope angle is also used to determine the dumping area and hence the dumping cost.

- **Swell factor and angle of repose:** Swell factor means how much the rock expands of its original volume after blasting. Angle of repose is the angle which a heap of material takes when dumped initially. These 2 factors should always be kept in mind while estimating the waste volumes and designing the dumps. Mostly Swell factor varies from 10-60% and angle of repose varies from 22-40^0.

- **Compaction provided during dumping**: Mostly during dumping of OB materials a dozer is used to give compaction to the dumped material. This will decrease the void ratio and will increase the FOS of the slope.

- **Cohesion:** Cohesion is defined as the resistance force per unit area. Its unit of measurement is Pascal (Pa). In natural soils, cohesion arises from electrostatic bonds between clay and silt particles. Thus if no clay and silt is present in soil then no cohesive forces exists. Typically for soils the cohesion values ranges in a few kPa. Rocks show much higher cohesion than soils. We can say that higher is the cohesion more is he FOS.

- **Angle of internal friction between particles:** It is defined as he angle between the normal force and the resultant force, when failure just occurs in reaction to a shearing stress. Alternately we can say it determines the ability of the soil to bear the shear stress. Mainly angle of internal friction depends on particle roundness and particle size in the dump. Lesser the roundness more is the friction angle and larger the median particle size more is the friction angle. If the quartz content of the sand is less than the frictional resistance to sliding is more as compared to sand with high quartz content. Overall we can say that higher is the angle of internal fiction more will be the FOS.

- **Soil content of the dump material:** Soil has a lower cohesion value as compared with any other OB material. Hence soil content of the dump material must be accurately determined.

- **Dump site topography:** The place where the OB is dumped is obviously going to affect the design of the dump. Usually most of the mine owner choose a flatter terrain to dump their OB. If the dump site is slightly sloppy than we must design some walls or dams to arrest the surface run-off from the dumps. Moreover a sloppy surface will tend to move the dumped material towards the down-stream side, hence decreasing its FOS.

- **Height of each deck and total dump height**: More is the dump height, less will be the factor of safety. The relation of FOS with the dump height is presented later in this thesis through modelling.

- **Method of dump construction**: The way of constructing the dump like: - Laying OB+ Fly-ash mixture in alternate layer of how much thickness, completely constructing the dump with a single mixture of OB+ Fly-ash, Applying compaction to the dumped material after how much time interval, will decide the dump slope stability.

- **Plantation and coir-matting practices carried out on the dumps**: Nowadays most of the mines are planting Vertebrae grass on the dump surface to enhance he slope stability. The nature of this grass is that above the surface it doesn't grow much but below the surface its roots spreads very deep. This will ensure that the roots will hold the dump material and during rainy season surface run-off will be prevented. Coir-matting is another practice which is coming up in most of the waste dumps. This will also prevent surface run-off.

- **Ground water condition**: Ground water have a tendency to reduce the cohesion and friction angle among the particles. Ground water present in joints, cracks, fractures will always alter the shear strength parameters and will give an upward thrust. This will tend to decrease the effective normal stress. As a result, overall the factor of safety will reduce to a great extent.

- **Time:** The time period for which the dumped material has to stand before being used for mine reclamation, is also an important governing factor in dump slope design. In other way we can say that as time progresses the dumped material will tend to settle down and after a particular time period there will be no movement. This can be seen during dump slope monitoring, as explained later in this thesis.

- **Dynamic forces:** Ground vibrations due to blasting can induce sufficient dynamic acceleration which will destabilize the slope. Usually the dumped site should be placed far away from the reach of any vibration wave. Earth quakes and other natural ground movements will also decrease slope stability.

2.2.2 Measures to Improve Dump Stability:

- OB compaction during dumping.
- Height of dump, preferably limited to 60 metres.
- Slope angle always maintained below angle of repose.
- Garland drains made near the dumps to minimize sliding menace due to water.
- Vertebrae grass plantation along the dump slope. The roots of this grass penetrates deep inside the dump material and holds it together.
- Jute and plastic covering of the dump top.

2.3 FLOW CHART SHOWING MATERIAL HANDLING DOMAIN

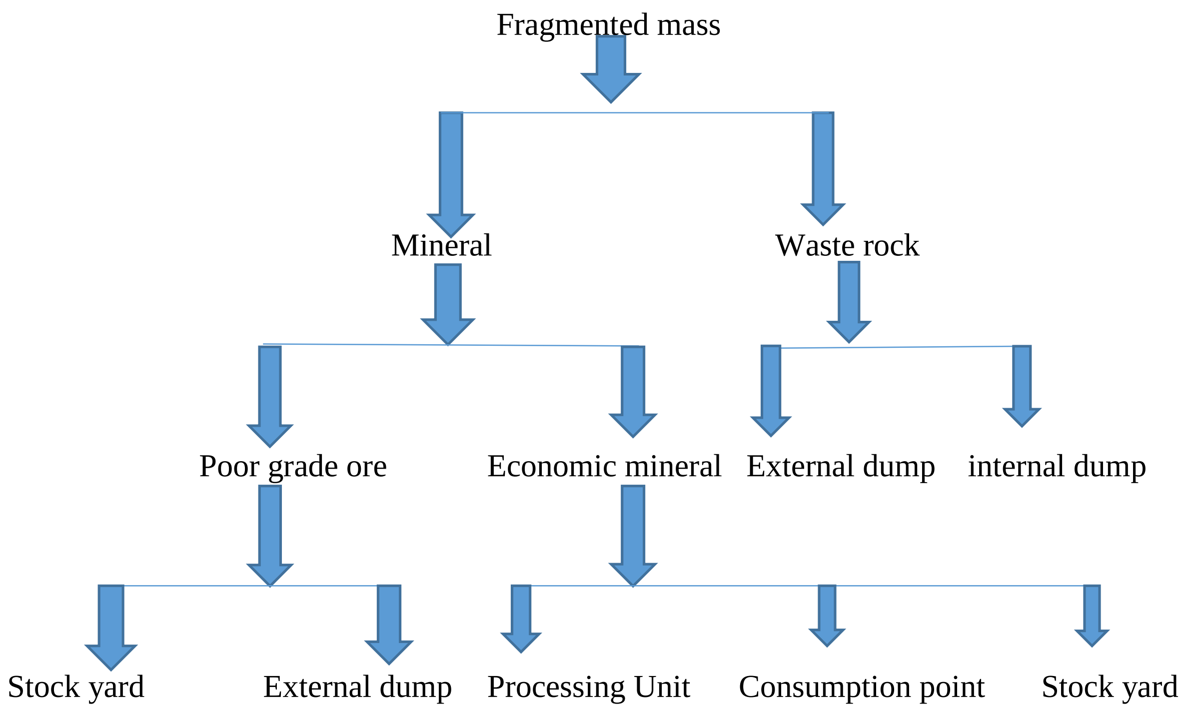

Figure 2.1: Plan of a material handling system

2.4 TYPES OF SLOPE FAILURE

Slopes mostly fail in 4 types of failure modes, as follows:-

- Circular failure/Non-circular failure
- Plane failure
- Wedge failure
- Toppling failure

Out of the above 4 types, mostly we see circular or non-circular types of failure in waste dumps. So I will concentrate mainly on Bishop's method of slices for finding Factor of Safety (FOS) for circular failure. This method of finding Factor of safety (FOS) is also used in OASYS software, which I have used for dump slope modelling.

2.4.1 Circular Failure

The condition under which circular failure occurs, arise when the individual particles in a soil or rock mass are very small compared with the size of the slope and these particles are not inter-locked. This type of failure only occurs for homogenous materials with uniform strength properties, unjointed rock masses or very highly jointed and very weak altered rock masses.

For every condition of a slope parameter there will be a slide surface for which the factor of safety is a Maximum. This surface is called 'Critical surface'. Various analysis methods have been proposed to find the critical surface.

Figure 2.2 below shows Bishop's method of slices for finding factor of safety and figure 2.3 below shows a typical slice with all the forces acting on it.

2.4.1.1 Bishop's method of slices for circular failure:-

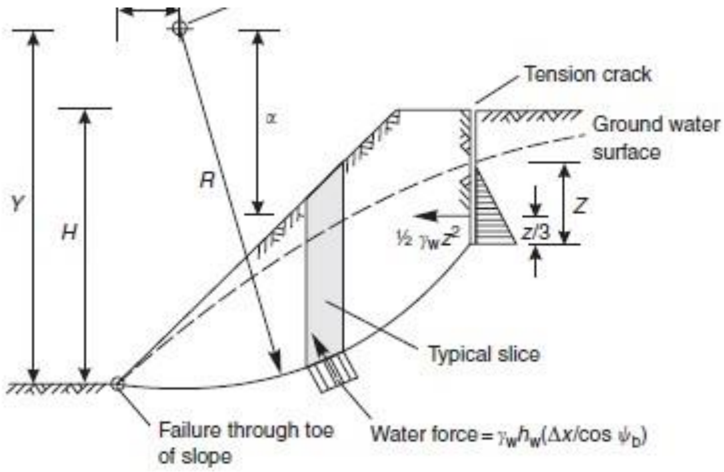

Figure 2.2: Bishop's simplified method of slices for finding FOS in circular failure (Wyllie and Mah, 2005)

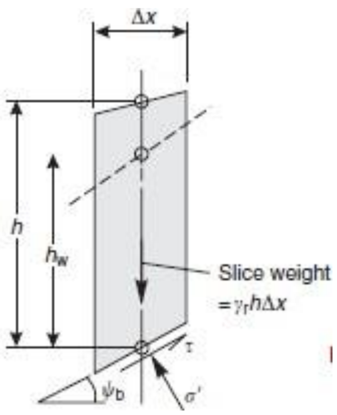

Figure 2.3: View of an individual slice (Wyllie and Mah, 2005)

In Bishop's method we are assuming that the slide surface is circular and the side forces are horizontal. The analysis must satisfy vertical forces and overall moment equilibrium. Charts are available to estimate the centre of the circle with Maximum FOS, but we need to do a series of iterations to find the Maximum FOS. Steps involved in calculating FOS by Bishop's method is as follows:-

- First the sliding mass is divided into a number of slices. Generally 5 slices are used for simple cases.

- Parameters which is needed to be defined for each slice is:-
  - Ψ_b, which is the base angle
  - W, which is the weight of each slice. It is given by multiplying the vertical height (h), the unit weight γ_r of the soil and the slice width Δx: $W = (h\ \gamma_r\ \Delta x)$.
  - A water pressure U, which is trying to lift the slice. This is given by the equation: - $U = (h_w\ \gamma_w\ \Delta x)$, where h_w indicates the height to the phreatic surface and γ_w indicates the unit weight of water.
- The shear strength parameters c and φ for the material lying at the base of the slice is calculated.
- The values of X, Y and Z for each slice is calculated and the expression for FOS is given by:- $FOS= [\Sigma x /(1 +Y/FOS)]/[\Sigma Z+Q]$ ------ (1)

  Where, $X = [c+ (\gamma_r\ h - \gamma_w\ h_w) \tan \varphi] (\Delta x/\cos \Psi_b)$,

  $Q=\frac{1}{2}\ \gamma_w\ z^2\ (\alpha /R)$

  $Z = \gamma_r\ h\ \Delta x \sin \Psi_b$

  $Y = \tan \Psi_b \tan \varphi$
- We must keep in mind that the following conditions must be fulfilled for each slice:-

  $\sigma' = [\gamma_r\ h - \gamma_w\ h_w - c (\tan \Psi_b /FOS)]/ [1+Y/FOS]$ ------ (2)

  $\cos \Psi_b (1 +Y/FOS) > 0.2$ ------ (3)

Bishop method of FOS calculation is an iterative process where initially we assume the FOS to be 1 and then iterate it by using equation 1, till we get a difference in FOS of current iteration and previous iteration within a tolerable limit.

Similarly Janbu method is used for calculating factor of safety for non-circular failure. For shallow slide surface with friction angle greater than 30^0, Janbu method gives a good estimate of FOS, but for slide surface with lesser friction angle Janbu method gives very poor estimate.

2.4.2 Plane Failure

Plane failure is rare in rock slopes and for dump slopes we can say it almost doesn't exists. But his failure gives us an insight to a simple 2-D case and helps us in analysing complex 3-D cases. The following geometrical conditions must be satisfied for plane failure to occur:-

- The sliding plane must have an angle of +/- 20^0 with the slope face. It means it is almost parallel to the slope face.
- The dip angle of the sliding plane must be less than dip angle of the slope plane. Alternately we can say, it must 'daylight' the slope face.
- The angle of friction of the sliding plane must be less than its dip angle.
- Upper portion of the sliding surface must end at the upper slope or in the tension crack.
- Failure can only occur in the sliding plane if it passes through the 'convex nose' of the slope.

Figure 2.4 shows the side-view of a plane failure and figure 2.5 shows a view of typical plane failure.

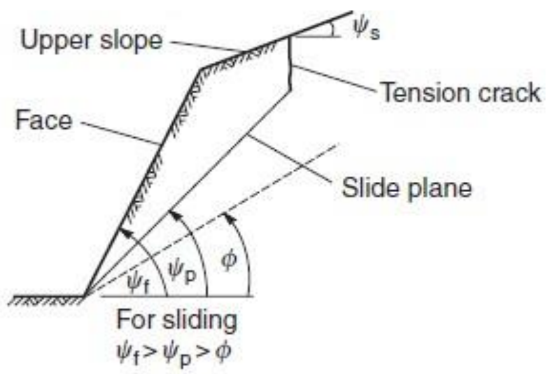

Figure 2.4: Cross-sectional view of a plane failure (Wyllie and Mah, 2005)

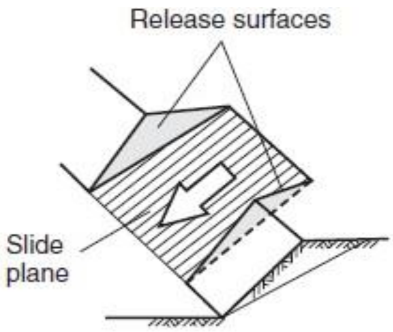

Figure 2.5: Release surface of a plane failure (Wyllie and Mah, 2005)

2.4.2.1 Limit equilibrium method for calculating factor of safety in case of plane failure

The material is assumed to be following Mohr- coulomb criteria and the shear strength is dependent only on cohesion (c) and friction angle (φ). Shear strength is given by the equation:- $\tau = c + \sigma' \tan \varphi$, where τ is shear strength, c is cohesion, σ' is effective normal stress and φ is angle of internal friction.

Factor of safety calculation for a plane failure can be represented by the following equation:-

FOS = Resisting force/Driving force

Resisting force= $cA + W \cos (\psi_p) \tan \varphi$ and driving force = $W \sin (\psi_p)$

Therefore, FOS= $[cA + W \cos (\psi_p) \tan \varphi] / [W \sin (\psi_p)]$

If water forces in the sliding plane and in the tension crack is taken then the above equation for FOS becomes, FOS= $[cA + (W \cos \psi_p - U - V \sin \psi_p) \tan \varphi] / [W \sin \psi_p + V \cos \psi_p]$

Where,

U is water force acting on the sliding plane = $.5\ \gamma_w z_w (H + b \tan \psi_s - z) \operatorname{cosec} \psi_p$

V is water force in the tension crack= $.5\ \gamma_w z_w^2$

2.5 OTHER METHODS OF SLOPE STABILITY ANALYSIS

2.5.1 Sensitivity Analysis

The parameters which influences the factor of safety has a wide range of values. What we have done in limit equilibrium analysis for calculating factor of safety is that, we have taken a single value for each of the influencing parameters. So in sensitivity analysis we can take a range for those parameters in calculating factor of safety. The actual concept of using sensitivity analysis is to find that which parameter has the greatest influence on factor of safety. For this we have to find the relationship between each of the parameters. If a particular problem contains more than 3 influencing parameters, than factor of safety calculation becomes difficult and tiresome. So the usual technique involves simultaneous analysis and judgement of the influencing parameters on factor of safety and then taking a judgement about appropriate factor of safety.

2.5.2 Probabilistic Design Method

This method is used to analyse how slope stability is affected by varying each influencing parameter. The probability of the slope failure is determined from the probability distribution of factor of safety. This method of stability analysis is applicable only when we have a large number of samples. If the sample number is less than the result might not be a representative of the actual condition. Basically in probabilistic design method we collect the opinions of the experts and then prepare the probability distribution function. So more the time the experts spend in analysing the data, the more accurate will be our probability distribution function. After analysis by the experts a probability density function for each parameter is prepared. A normal distribution curve is usually adopted, where the mean represents the most commonly occurring value of that parameter. Then the probability of failure is calculated by 2 simple methods: - Margin of safety method and Monte-Carlo method.

2.6 GUIDELINES AS PER CMR

In CMR 1957, regulation number 98 clearly states the following for opencast workings:-

- In alluvial soil, morum, clay, gravel, debris or any other similar structure the overall slope angle shouldn't exceed 45^0. The figure is flexible to the decision of the regional inspector.
- The bench height of the above mentioned structures shouldn't be greater than 1.5 metre and width of the bench should always be greater than height.
- For coal slopes the overall slope angle shouldn't exceed 45^0 and the height of each bench shall be less than 3 metres. The bench width should always be greater than the height.
- In any kind of hard excavation, the sides must be suitably benched, sloped and secured so as to prevent any danger from falling material.
- If undercutting any side causes overhanging, than such undercuts must be avoided.

Regarding stability of slopes, the directorate general of mine safety has enforced certain guidelines as follows:-

- A scientific study should be carried out to plan and design a mechanised open-cast working, including the overall slope angle of the pit.
- Overburden consisting of Alluvium or any soft soil shall be benched at a height less than 5 metres and the bench width shall be at least 3 times the bench height.
- The height should be planned in such a way that it is in the reach of excavation machines.
- The topsoil removed during mining shall be stacked separately. In future this can be used for reclamation purpose.

- .The slope of an overburden dump is usually determined by the angle of repose of the material, but in no case it should exceed 37.5^0. Alternately we can say, bench angle shouldn't exceed the natural angle of repose or 37.5^0, whichever is less.
- Width of a bench shall not be less than:-
    a) Breadth of the widest machine employed in the bench plus an extra margin of 2 metres.
    b) If dumpers are moving on the bench, then 3 times the width of the dumper.
    c) Bench height, whichever is more.
- Any overburden dump exceeding 30 metres in height shall be suitably benched in decks, so that height of each deck is 30 metres maximum.
- The overall slope shall be less than 1 vertical to 1.5 horizontal.
- Loose soils, materials or rejects from washeries shall be dumped in such a manner that there is least possibility of sliding.
- The bottom of a waste dump shall not lie within the radius of 45 metres from any mine opening, public road, railway or other permanent structure not belonging to the owner.

2.7 OVERVIEW OF NUMERICAL MODELLING

2.7.1 FLAC SLOPE

FLAC SLOPE is a mini-version of Flac that is used to calculate factor of safety for slope stability analysis. It is designed to provide an alternative to 'limit equilibrium' method of analysis. Instead FLAC SLOPE works on a technique of 'Shear strength reduction'. Basically it changes the strength properties and performs a series of calculation to find FOS. Thus it provides a full solution of the coupled stress/displacement, equilibrium and constitutive equations. [6]

With some advantages this software also provides certain disadvantages. The main disadvantage is that it takes more time than a limit equilibrium programme, to determine factor of safety. But nowadays many faster processors are being developed, so calculation of the critical failure surface by this software is done in a reasonable time. Certain important advantages of this software include:

- We need not specify any artificial parameters like inter-slice force angles for FOS calculation.
- If a particular condition is favouring multiple failure surface, then this software will generate it naturally.
- Any reinforcing elements are also modelled in this software as an integral part of real in-situ conditions and they are not merely treated as equivalent forces.
- The mechanisms adopted to get the solutions in this software are kinematically feasible. But in limit equilibrium method only forces are considered, not the real kinematics.

2.7.1.1 Stages for calculating factor of safety

Basically it consists of 4 stages, namely:

- Defining the model: From the GUI we can add new model and give its dimensions.
- Building the model: In this stage we can add layers, give material properties, add materials to the layer, position water table, install reinforcement etc.
- Solving the model: In this stage FOS calculation is performed by considering either coarse, medium or fine grain size. Cohesion and friction angle is taken in calculation of FOS.
- Plotting the result: After solving we need to plot the result to analyse the movement rate of various particles in the slope. This can be saved for future use.

2.7.1.2 Procedure of calculating factor of safety

It works on the principle of 'Shear strength reduction technique'. In an iterative manner it decreases the shear strength of the material to achieve a limiting equilibrium condition. The steps involved are:

- First the cohesion is set to a very large value and 'representative number of steps' (N_r) is calculated. This will determine the response time of the system.
- A FOS_{trial} is assumed and N_r steps are run. If the 'Unbalanced force ratio' is smaller than 0.001, the system is assumed to be in a state of equilibrium. The loop ends here.
- If 'Unbalanced force ratio' is greater than 0.001 then, another N_r steps are run. For this the FOS_{trial} is increased.
- The average value of the 'Unbalanced force ratio' for 2 consecutive iterations are compared. If it is less than 10%, then the loop ends with non-equilibrium factor of safety.

2.7.2 OASYS

The primary function of this software is to analyse the slope stability. An option is available in this software to include the soil reinforcement and calculate earth pressure and bearing capacity problems [11]. We can model both soil and rock slopes which shows circular as well as non-circular failure.

2.7.2.1 Stages in calculating factor of safety

- A new model wizard is created and all the required details and description of the model is given.
- Then material properties are defined and stratums are created. We also have to specify the pore water pressure.
- Then the slip surfaces are defined and specifications about the circle radius is given.

- Here by default the minimum number of slices to be taken for analysis is 25 and maximum iteration is 300. These figures are flexible.
- After defining all the above steps, we analyse the model and this gives all the possible slip surface and displays the minimum factor of safety.

2.7.2.2 Procedure of calculating factor of safety

For Circular failure, the method of analysis in OASYS software is as follows:-

- Bishop's horizontal inter-slice forces method.
- Bishop's parallel inclined inter-slice forces method.
- Bishop's variably inclined inter-slice forces method.

Bishop's variably inclined inter-slice forces method gives accurate analysis, so usually this method is preferred for factor of safety calculation. This method assumes that each slice is in a state of horizontal and vertical equilibrium. Also moment equilibrium exists for each slice. An initial factor of safety is assumed. Now the iteration starts and after each round of iteration, the inclinations of the inter-slice forces are varied (but individual stability of each slice is not affected), to arrive at an overall horizontal, vertical and moment equilibrium. As we are changing the inclination of inter-slice force, the driving and resisting forces change. This changes the factor of safety until the factor of safety of previous iteration and current iteration is less than a specified value. After this the minimum factor of safety is displayed.

2.8 SLOPE MONITORING

Sometimes a slope in a quasi-stable condition doesn't fail, but in other cases a minor slope movement can lead to entire collapse and fatal accident. As we can't predict the nature of the slope, so a systematic monitoring programme can be helpful in controlling slope hazard. Various types of monitoring equipment's are available in the market and depending on the economic feasibility, accuracy and dump type the mine owner decides the monitoring equipment. Some of the common monitoring equipment's are as follows:-

1) Survey network like total stations- A total station is an electronic survey equipment which can perform horizontal and vertical measurements with reference to mine grid system. We can say that a total station is combination of electronic theodolite, electronic distance measurement, built-in data collector and a micro-processor. It is more efficient and accurate as compared to normal theodolite. A total station measure the horizontal angle, vertical angle and slope distance. Then it calculates horizontal distance, vertical distance, (X, Y, Z) co-ordinates and azimuths of lines. The main advantages of using a total station is as follows:

- Information can be collected relatively more quickly.
- We can perform more than one survey by placing the total station in one location.
- It is easy to measure horizontal distance with simultaneous northing easting and elevation.
- It is easier to upload the design data from CAD programs to data collector.
- The measuring site of the total station can be set quickly and efficiently.

Though there are many advantages of using total station, still few disadvantages exists as follows:-

- There must be a line of sight between the total station and the point of measurement.

- For large scale projects the rectangular co-ordinate system must be transformed into geographic co-ordinate.

2) Tapes, crack meters and pins: For monitoring the expansion of tension crack sometimes flags or pins are inserted on both ends of the tension crack. Two stacks can also be driven on either side of the tension crack and distance between the two stacks can be measured by an appropriate rod.

3) Wire line extensometer: It is also used to measure the movement across tension crack. It comprises of a wire fixed in the unstable part of the ground. The stable part of the ground contains the monitor and pulley station. The wire in the unstable part is tied with a tensioning weight. As displacement occurs the wire moves and the weight also moves up. This reading is noted to find the displacement. Sometime alarms are set up to know the threshold limit of displacement.

4) Inclinometers: It consists of a casing, which has its lower end fixed to a stable ground. Due to ground movement the casing will have lateral displacement and this is sensed by a sensor. Thus, we can say that the inclinometers are used to locate shear zones, determine shearing is planar or rotational and whether the shearing is accelerative, deccelerative or constant.

5) Time domain reflectometry (TDR): Here first a co-axial cable is fixed in a drill hole and then through it electronic pulses are sent. When there is any deformation in the rock mass a reflected signal is sent back. This signal gives the information about the sub-surface deformation. The main advantage of TDR is that, we can go for rapid, remote and complex monitoring.

6) Bore-hole extensometers: Here basically the change in distance between the anchors and bore-hole collars are detected. This will give us an idea about the displacement of the rock mass. If we know the structural factors which will have major influence on slope stability, then bore-hole extensometer is a useful instrument. We must also remember that this is one of the costliest instruments.

7) **GPS:** This method is applicable for slope movement if it occurs in a large area and much accuracy is not required. For GPS measurement stations are constructed on slide and their co-ordinates are obtained at any desired frequency with reference to the GPS unit. As it is a low cost set-up and easy to set, so most of the total stations are now being replaced by GPS measuring unit.

8) Synthetic aperture radar (SAR): It is the most accurate and expensive method and involves remote sensing technique. It captures radar image of the ground surface and with time a comparison is made with these images. The image covers an area of 2500 km^2 and movement up to 5mm can be detected. The measurement is independent on sunlight, rain, snow, fog etc.

2.9 SLOPE STABILITY ANALYSIS BY OTHER INVESTIGATORS

Table 2.1: Work done by other investigators

Year	Author	Title	Description
2014	Vinoth, L Ajay kumar	Applying real time seismic monitoring technology for slope stability assessment- An Indian open cast coal mine perspective.	Carried out real time monitoring of a high-wall mine to identify the impact of seismic activity on high-wall slope. He prepared seismic event impact contours and seismic clusters to know the impact of underground development work on the high-wall slope. During his monitoring period he found out that, the overall impact of the micro-seismic activity on the slope was negligible and no high-wall slope stability problem was created.
2012	Prof. Singam Jayanthu	Field monitoring of stability of dump with 25% fly-ash and 75% overburden materials related to JPOCCM mine, JPL.	Carried out stability analysis of overburden mixed with 25% fly-ash in alternate layer. Dry density, Cohesion and friction angle value as obtained by them through experimental analysis for OB material were 1.87g/cc, 41.8 KN/m^2 and 28.5^0 respectively. Similarly dry density, Cohesion and friction angle value as obtained by them through experimental analysis for OB+25% fly-ash mixture were 1.74g/cc, 89.6 KN/m^2 and 22.9^0 respectively. With this value they modelled the dump in PLAXIS software, with 4 decks and each deck is of 30 metre height and 32^0 deck angle. The overall slope angle was fixed at 22^0. A factor of safety of 1.75 was obtained. When a top soil layer of 2 metre

			was put above it the factor of safety increased to 1.78. This shows that the 2 metre top soil layer added to the stability of the dumps.
2011	Shad M. Sargand, Farid A. Momand	Feasibility of using cone pentrometer truck to install Time domain reflectometry and fibre optic slope failure Detectors in pavement structures	Time domain reflectometry (TDR) technique was used by a RUSS professor of civil engineering, Ohio University, to monitor the slope stability of embankments in the year 2011. His study also included the use of Fibre optic slope failure detectors. The main objective of this study was to compare Optical time domain reflectometry (OTDR) with electrical TDR and to demonstrate a new method of installation of fibre optic or co-axial cables in earthen slopes, to monitor slope stability problems.
2005	Dr Neal Harries, Dr David Noon, Mr Keith Rowley	Case studies of slope stability radar used in open cut mines	Slope stability radar (SSR) was used to manage the risks associated with slope instability in Mount Owen coal mine dumps of Australia. The monitoring was carried out by a group of persons from the South-African institute of mining and metallurgy on 13th January 2005. The SSR was made up of several alarms, with one urgent alarm for 70mm Maximum movement over a time period of 45 minutes. The scanned pixel area of the alarm was 1029 m^2. The red alert was first sounded before the actual dump slope failure. As the SSR was implemented, the overburden haulage over the low wall

			dump was ceased 2 hours 40 minutes prior to the actual slump or fail.
2005	Dr Neal Harries, Dr David Noon, Mr Keith Rowley	Case studies of slope stability radar used in open cut Mines	Carried out an investigation in South-African metal mines, for dump and slope stability analysis. It was done in the year 2005. The monitoring technique used was slope stability radar (SSR). Four alarms were set in the SSR, namely- red, orange, yellow and green, to make the pit superintendent aware of various conditions. A rock fall was seen on the SSR visual, which was concluded from the SSR deformation plot, to be a result of 54mm for over 240 minutes. As the SSR system provided an hour of warning with a small movement of the rock mass, so all the machinery and personnel could be cleared from the place.
1999	Helmut Rott, Bernd Scheuchal and Andreas Siege	Monitoring very slow slope movements by means of SAR interferometry: A case study from a mass waste above a reservoir in the Otztal Alps, Austria	Carried out monitoring of very slow slope movement of a mass waste above the Gepatsch hydropower reservoir situated in the Kanaur valley, Austria. They used synthetic aperture radar (SAR) interferometry to detect slope movement, which were in the order of some few millimetres to centimetres. The study was carried out between July 1992 to August 1998, by using two satellites namely- ERS-1 and ERS-2. Above a particular height the motion was detected by interferograms while the motion of the lower slope section

			was measured by ground based geodetic measurements. From the interferometry analysis it was found that the wasting process affects the total slope of 1000 metre height.
1987	Alistair Kent	Coal mine waste dumps in British Colombia stability issues and recent development	Proposed two dump slope monitoring technique in British Colombia coal mine. The two methods are using simple wire-line extensometer on the dump crest and wire-line monitor record. Both this techniques are till now prevalent in British Colombia mines. After the installation of wire-line extensometer on the dump crest accidents due to dump failure have greatly reduced. Another experimental technique successfully implemented was an automated wire-line extensometer, making use of truck dispatch and telemetry system.

CHAPTER 3

GEO-MINING DETAILS

3.1 MINE A

KTK open-cast coal mine belongs to Sinagreni Collieries Company limited (SCCL). This mine is located 3 km away from Bhupalapalli. The total lease hold area of the mine is 336 ha and working depth is 85 metres. The mine has a total of five coal seams. In the year 2009, production started in the mine, with the target for the financial year being 1.2 million tonnes of coal. It also planned to remove 13 million m^3 of overburden material. The stripping ratio for the mine is between 10:1 and 12:1. The 50000 tonne per month production of the mine is taken to Kakatiya thermal power station, which is located on Bhupalapalli-Warangal PWD road. The total distance from the mine to the power station is 15km. The power plant is producing 2200 tonnes per day of fly-ash and 600 tonnes per day of bottom-ash. The current capacity of the power plant is 500 MW and in future it is going to increase to 1100 MW. This means more amount of fly-ash and bottom-ash is going to be generated.

The overburden material was carried from the mine site to the dump ground by dumpers. Fly-ash is brought from APGENCO thermal power plant located 15 km away from the mine. For 30% fly-ash in the mixture, nearly 1 truck of fly-ash is put after 3 trucks of overburden material. Then the dumped material is dozed to get a homogenous mixture of OB and fly-ash. This method is repeated until the boundary of the dump area is reached.

3.2 MINE B

JPL coal mine is an open-cast captive coal mine located in Raigarh district of Chhattisgarh. This mine is only 60 km away from Raigarh town. The lithology of the flat coal seam is comprised of 3-4 m top soil and below it 3-8 m weathered sandstone. This weathered sandstone is loose in nature and can be excavated without drilling and blasting. After this section the rock is hard, compact and massive. To remove this we require blasting. These all excavations extend up to 16 m.

Two coal sub-blocks are found here. The dip of the IV/2 and IV/3 coal sub-blocks are 2-6^0 and strike direction is in NW-SE. It has one small fault of throw 0-15 m. These sub-blocks have 10 number of coal seams numbered X-I in descending order. Currently the depth of the mine is 36 m. It has 6 benches each of 6 m height. Final depth of the pit is planned to be 120 m. Width of the bench is kept at 20 m and gradient of the ramp is 1 in 16. Backhoe type excavator is used in conjunction with dumpers to excavate the bench. Overburden material is carried to the dump site by Dumpers.

First a row of OB material was dumped all around the proposed area. The width of the initial row was greater than 15 m and 5 m in height. Then fly-ash mixed with 25% OB was dumped and a layer of 5 m thickness is formed. This is continued till a height of 30 m is reached. So a total of 6 layers in each bench is possible. The total height of the dump is proposed to be 120 m, but till now only 72 m dump was formed with 25 m deck height. The deck angle is kept at 28^0, width at 40 m and overall slope angle at 21^0.

CHAPTER 4

NUMERICAL MODELLING

4.1 MODELLING OF MINE A

4.1.1 OASYS

Here I have taken only 1 deck to do modelling in OASYS software. I have taken 3 conditions for the deck material, that is ‘only overburden’, ‘overburden plus 15% fly-ash’, ’overburden plus 30% fly-ash’. For each condition again 3 sub-conditions are there where I have varied the height of the deck and for each height a bench angle is found out which gives critical factor of safety (factor of safety >1.2).

From the previous experiments conducted by Sir Raj chakravarty, I have taken the Maximum dry density, Optimum moisture content, Cohesion and Friction angle data for all the 3 conditions mentioned above.

The base of the dumped material is assumed to be of Sandstone whose dry density is 2.2 g/cc and wet density is 2.4 g/cc. Its friction angle is assumed to be 32^0 and cohesion to be 1000 KN/m^2. For all the 3 conditions mentioned above this assumption will hold good.

4.1.1.1 Condition1- the Dumped material is only overburden

The Maximum dry density, Optimum moisture content, Cohesion and Friction angle is taken from the experimental data as 2.02g/cc, 9.16%, 2.85 KN/m^2 and 30.84^0 respectively. The wet density is calculated from the above data as 2.205g/cc. Figure 8, 9 and 10 shows the factor of safety calculation for 30, 20 and 10 metre bench height respectively by OASYS software.

- **Height of the deck is fixed at 30 metre**

Table 4.1: For OB bench, variation of FOS with bench angle (30 metre bench height)

Deck Angle (in degrees)	Factor of safety
20	1.801
25	1.430
26	1.372
27	1.319
28	1.267
29	**1.222**
30	1.176
35	0.99
40	0.845
45	0.728

-

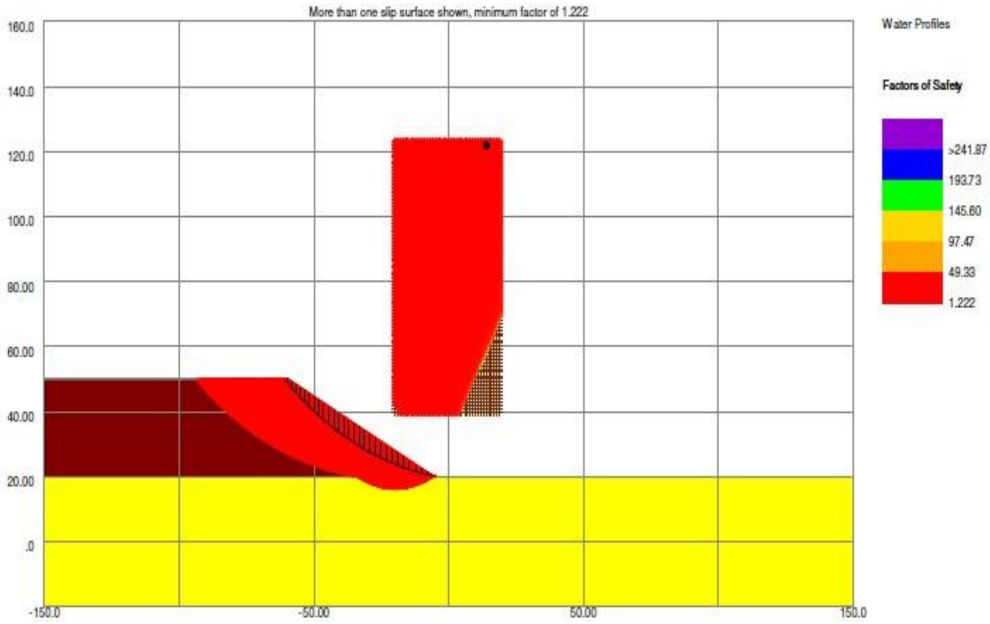

Figure 4.1: FOS for 30 metre OB bench at 29^0 bench angle using OASYS (minimum FOS is 1.222)

- **Height of the deck is fixed at 20 metre**

Table 4.2: For OB bench, variation of FOS with bench angle (20 metre bench height)

Deck Angle (in degrees)	Factor of safety
20	1.852
25	1.479
26	1.418
27	1.364
28	1.315
29	1.265
30	**1.221**
35	1.03
40	0.885
45	0.767

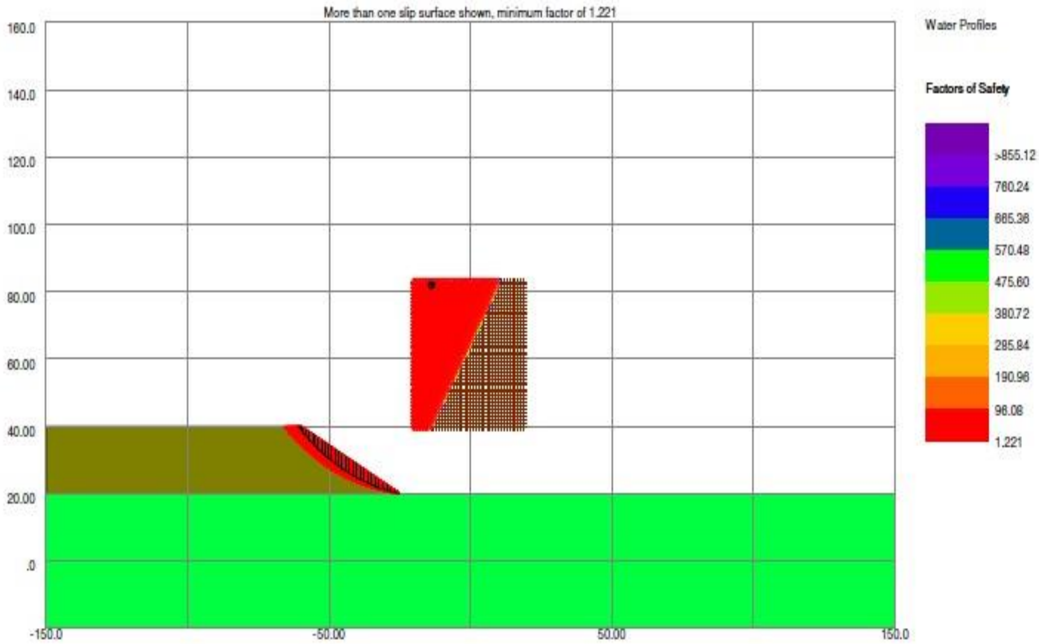

Figure 4.2: FOS for 20 metre OB bench at 30^0 bench angle using OASYS (minimum FOS is 1.221)

- **Height of the deck is fixed at 10 metre**

Table 4.3: For OB bench, variation of FOS with bench angle (10 metre bench height)

Deck Angle (in degrees)	Factor of safety
20	1.972
25	1.592
26	1.532
27	1.477
28	1.425
29	1.376
30	1.330
35	1.137
40	0.987
45	0.866

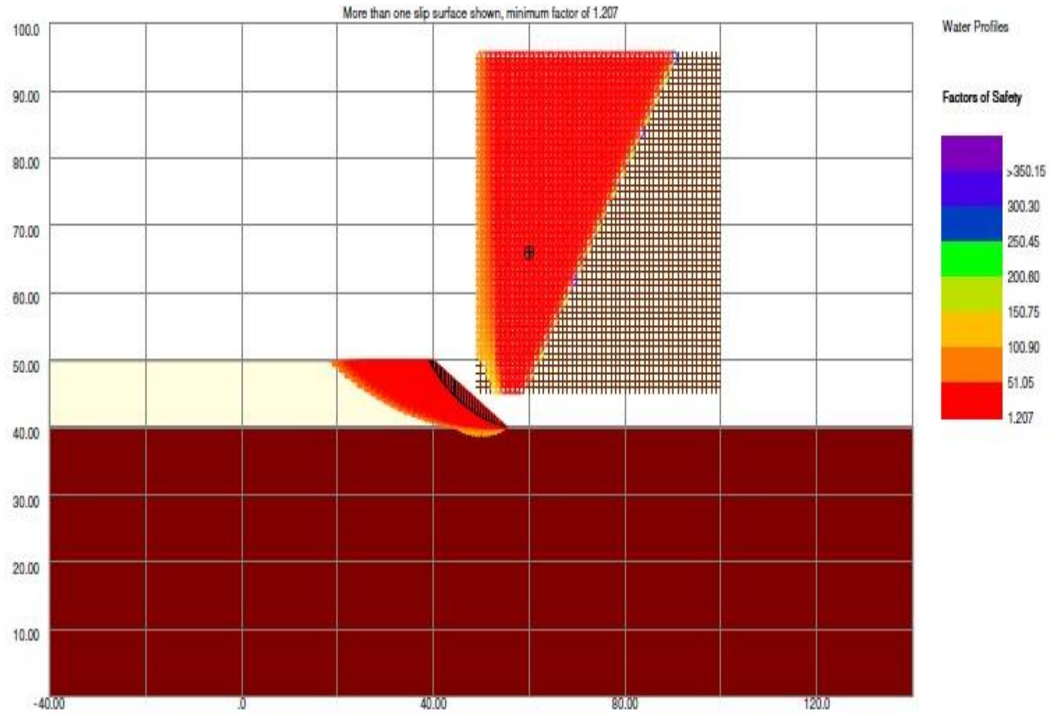

Figure 4.3: FOS for 10 metre OB bench at 33^0 bench angle using OASYS (minimum FOS is 1.207)

Table 4.4: Safe bench angle for OB dumps at different bench height

Bench height (in metres)	Maximum Safe Bench angle (in degrees)
30	29
20	30
10	33

4.1.1.2 Condition 2:- The Dumped material is OB+15% fly-ash

The Maximum dry density, Optimum moisture content, Cohesion and Friction angle is taken from the experimental data as 1.91g/cc, 10.11%, 7.51 KN/m^2 and 25.59^0 respectively. The wet density is calculated from the above data as 2.103g/cc. Figure 12, 13 and 14 shows the factor of safety calculation for 30, 20 and 10 metre bench height respectively by OASYS software.

- **Height of the deck is fixed at 30 metre**

Table 4.5: For OB+15% fly-ash deck, variation of FOS with bench angle (30 m bench height)

Bench angle (in degrees)	Factor of safety
20	1.641
25	1.323
26	1.269
27	**1.223**
28	1.179
29	1.137
30	1.100
35	0.943
40	0.821
45	0.722

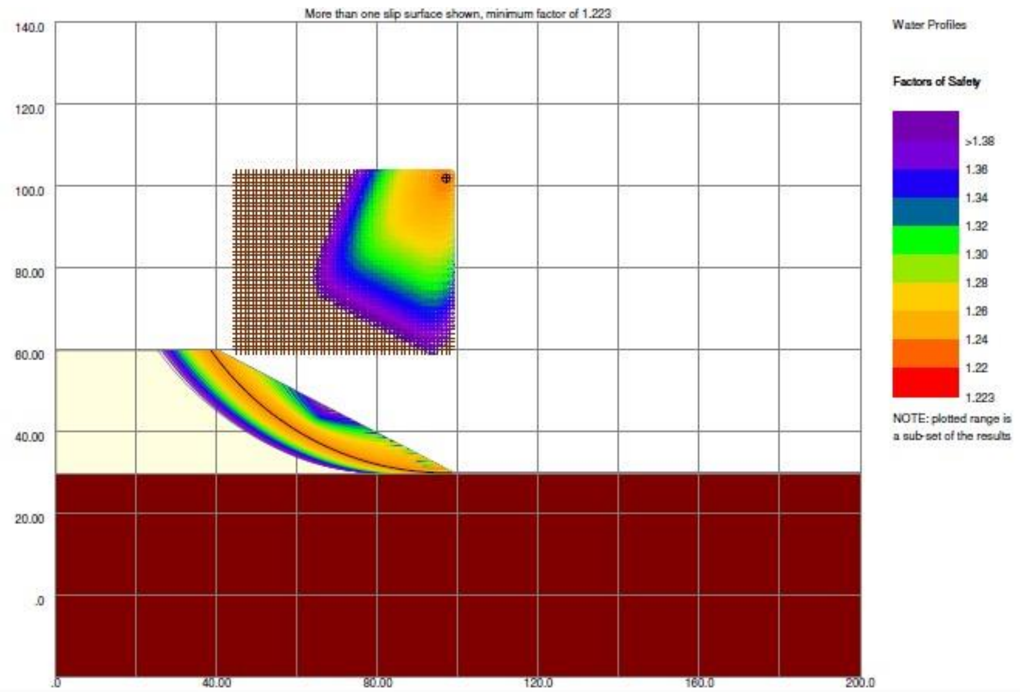

Figure 4.4: FOS for 30 metre OB+15% Fly-ash bench at 27^0 bench angle using OASYS (minimum FOS is 1.223)

- **Height of the deck is fixed at 20 metre**

Table 4.6: For OB+15% fly-ash deck, variation of FOS with bench angle (20 m bench height)

Bench angle (in degrees)	Factor of safety
20	1.733
25	1.391
26	1.341
27	1.296
28	1.253
29	**1.213**
30	1.176
35	1.019
40	0.892
45	0.793

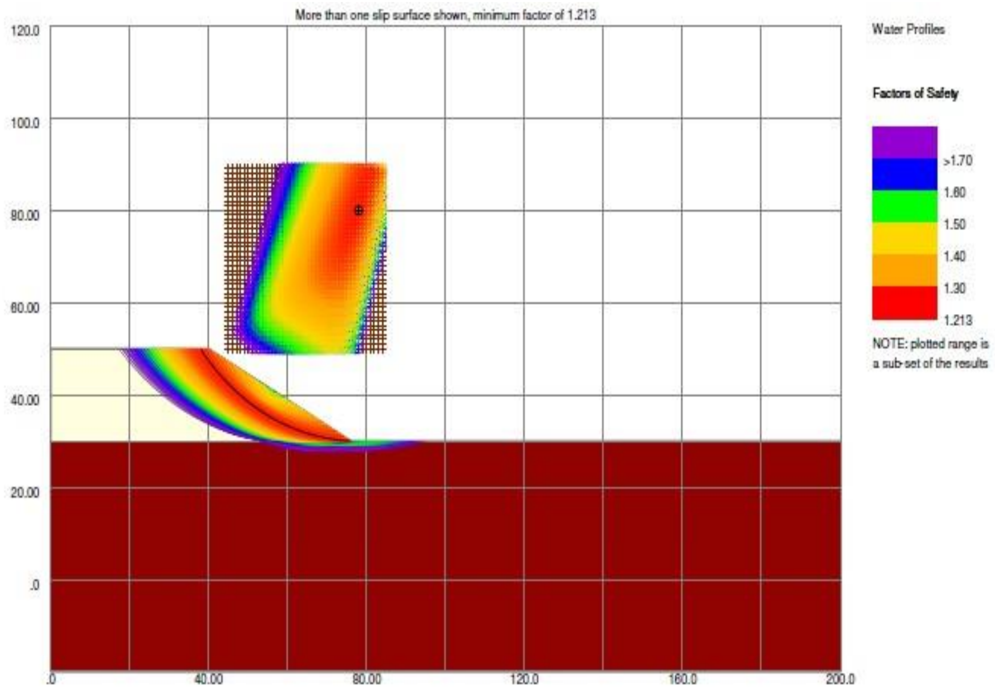

Figure 4.5:- FOS for 20 metre OB+15% Fly-ash bench at 29^0 bench angle using OASYS (minimum FOS is 1.213)

- **Height of the deck is fixed at 10 metre**

Table 4.7: For OB+15% fly-ash deck, variation of FOS with bench angle (10 m bench height)

Bench angle (in degrees)	Factor of safety
20	1.963
25	1.622
26	1.569
27	1.519
28	1.474
29	1.430
30	1.390
35	**1.220**
40	1.089
45	0.987

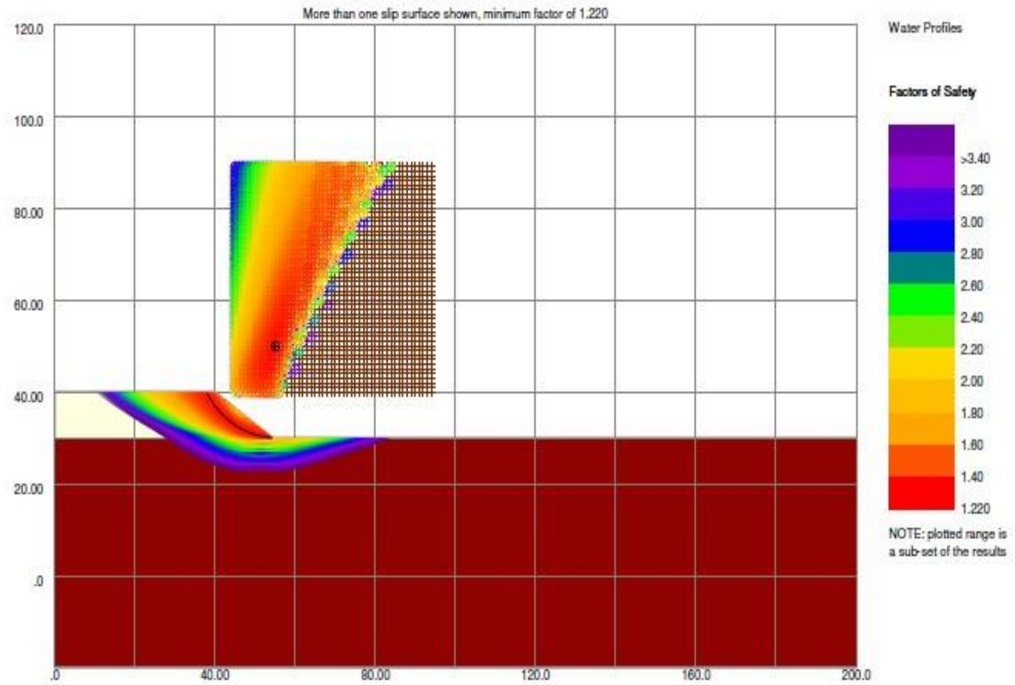

Figure 4.6: FOS for 10 metre OB+15% Fly-ash bench at 35^0 bench angle using OASYS (minimum FOS is 1.220)

Table 4.8: Safe bench angle for OB+15% fly-ash dumps at different bench height

Bench height (in metres)	Maximum Safe bench angle (in degrees)
30	27
20	29
10	35

4.1.1.3 Condition 3:- The Dumped material is OB+30% fly-ash

The Maximum dry density, Optimum moisture content, Cohesion and Friction angle is taken from the experimental data as 1.70g/cc, 15.95%, 6.47 KN/m^2 and 26.87^0 respectively. The wet density is calculated from the above data as 1.97g/cc. Figure 16, 17 and 18 shows the factor of safety calculation for 30, 20 and 10 metre bench height respectively by OASYS software.

- **Height of the deck is fixed at 30 metre**

Table 4.9: For OB+30% fly-ash deck, variation of FOS with bench angle in 30 metre bench

Bench angle (in degrees)	Factor of safety
20	1.712
25	1.380
26	1.327
27	1.278
28	**1.229**
29	1.187
30	1.145
35	0.981
40	0.852
45	0.750

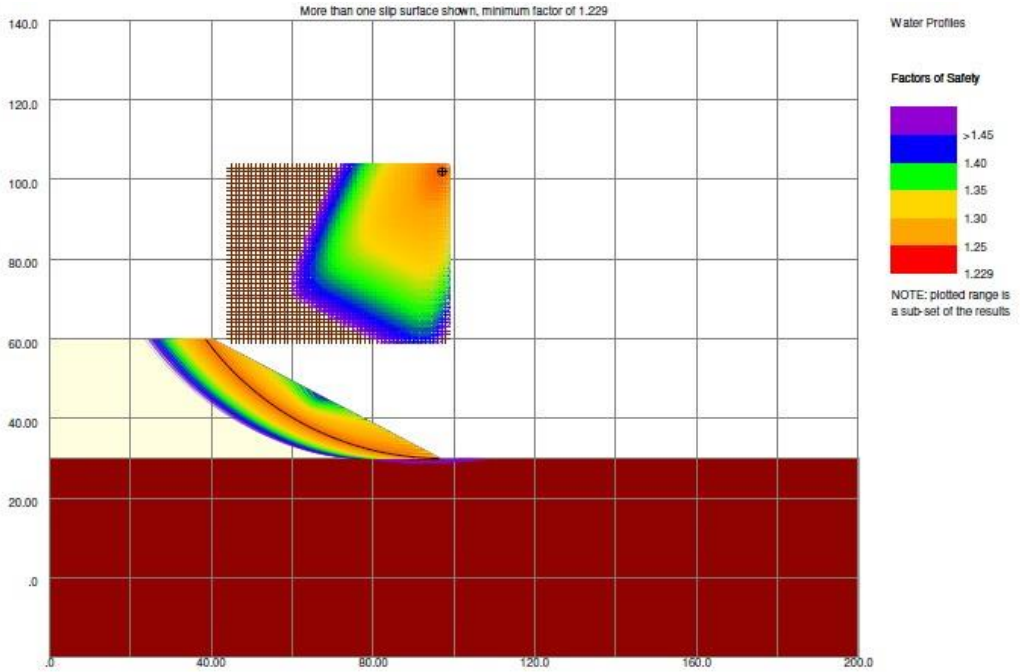

Figure 4.7: FOS for 30 metre OB+30% fly-ash bench at 28^0 bench angle using OASYS (minimum FOS is 1.229)

- **Height of the deck is fixed at 20 metre**

Table 4.10: For OB+30% fly-ash deck, variation of FOS with bench angle in 20 metre bench

Bench angle (in degrees)	Factor of safety
20	1.788
25	1.448
26	1.397
27	1.349
28	1.304
29	1.262
30	**1.223**
35	1.057
40	0.923
45	0.819

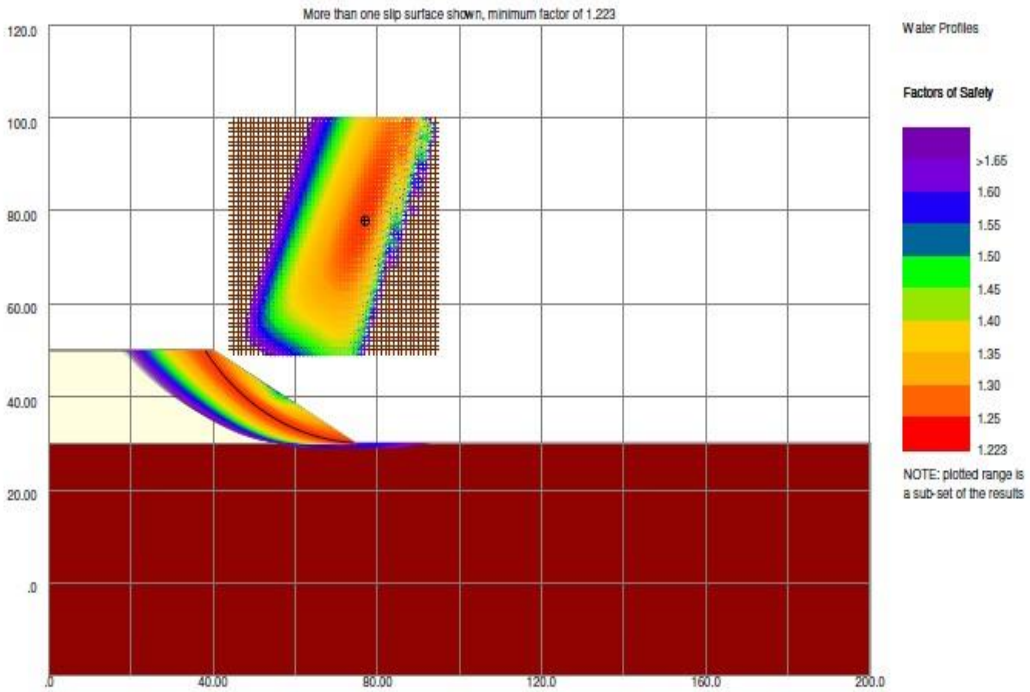

Figure 4.8: FOS for 20 metre OB+30% fly-ash bench at 30^0 bench angle using OASYS (minimum FOS is 1.223)

- **Height of the deck is fixed at 10 metre**

Table 4.11: For OB+30% fly-ash deck, variation of FOS with bench angle in 10 metre bench

Bench angle (in degrees)	Factor of safety
20	2.033
25	1.677
26	1.620
27	1.569
28	1.520
29	1.475
30	1.433
35	1.259
40	1.121
45	1.012

Figure 4.9: FOS for 10 metre OB+30% fly-ash bench at 36^0 bench angle using OASYS (minimum FOS is 1.223)

Table 4.12: Safe bench angle for OB+30% fly-ash dumps at different bench height

Bench height (in metres)	Maximum Safe bench angle (in degrees)
30	28
20	30
10	36

4.1.2 FLAC SLOPE

All the data as taken in OASYS software for all the 3 conditions is kept same. The boundary condition is also kept same.

4.1.2.1 Condition 1:- The Dumped material is only OB

- **Height of the deck is fixed at 30 metre**

Table 4.13: For OB bench, variation of FOS with bench angle (30 metre bench height)

Bench angle (in degrees)	Factor of safety
20	1.73
25	1.42
26	1.38
27	1.31
28	1.26
29	**1.23**
30	1.19
35	1.03
40	0.84
45	0.77

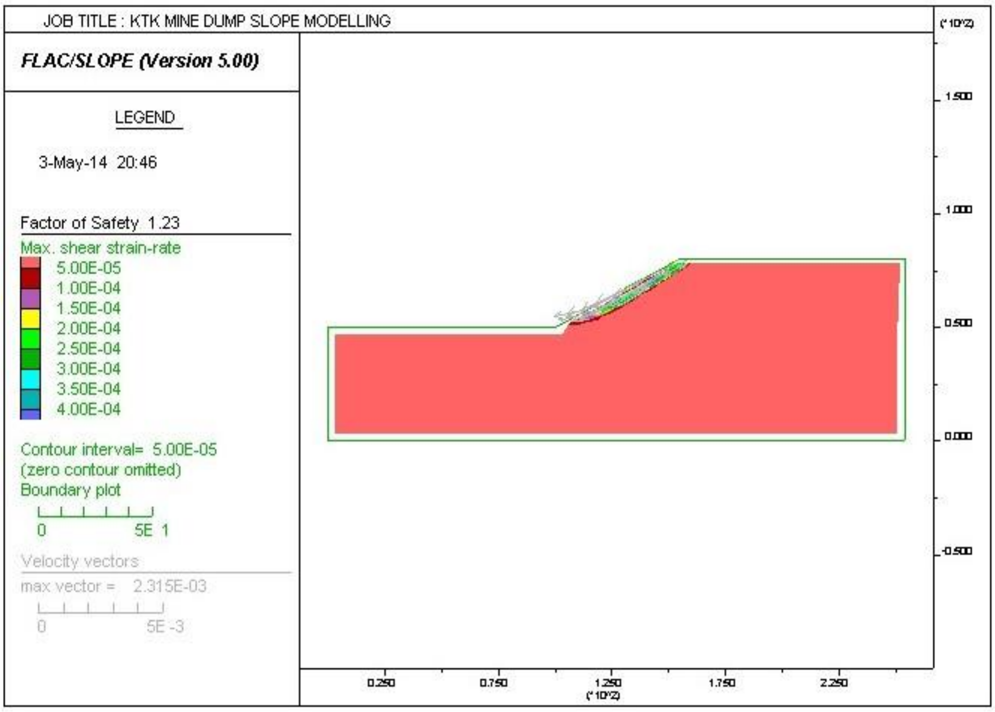

Figure 4.10: FOS for 30 metre OB bench at 29^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 20 metre**

Table 4.14: For OB bench, variation of FOS with bench angle (20 metre bench height)

Bench angle (in degrees)	Factor safety
20	1.66
25	1.51
26	1.45
27	1.40
28	1.35
29	1.31
30	1.27
35	1.10
40	0.99
45	0.87

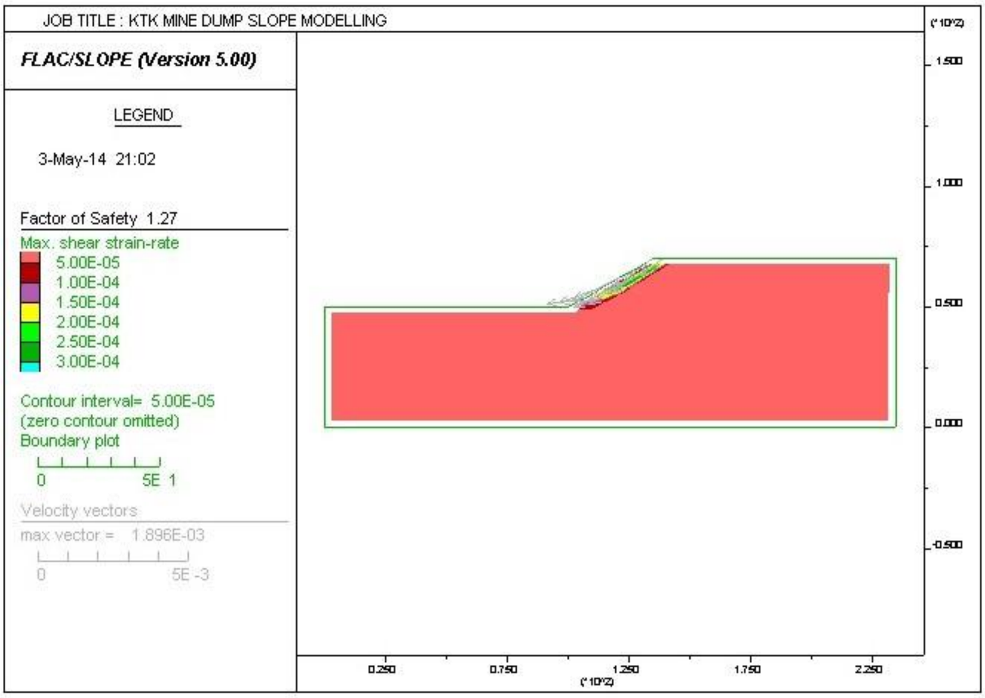

Figure 4.11: FOS for 20 metre OB bench at 30^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 10 metre**

Table 4.15: For OB bench, variation of FOS with bench angle (10 metre bench height)

Bench angle (in degrees)	Factor of safety
20	1.72
25	1.81
26	1.76
27	1.71
28	1.67
29	1.62
30	1.57
35	1.37
40	**1.22**
45	1.13

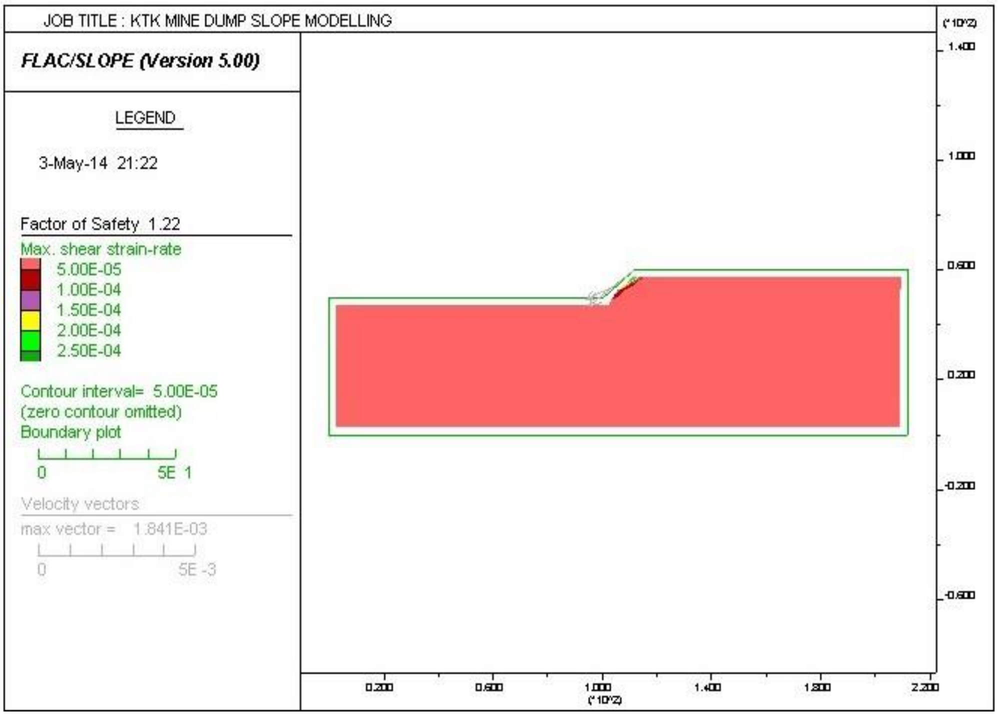

Figure 4.12: FOS for 10 metre OB bench at 40^0 bench angle using FLAC SLOPE

Table 4.16: Safe bench angle for OB dumps at different bench height

Bench height (in metres)	Maximum Safe bench angle (in degrees)
30	29
20	31
10	40

4.1.2.2 Condition 2:- The Dumped material is OB+15% fly-ash

- **Height of the deck is fixed at 30 metre**

Table 4.17: For OB+15% fly-ash bench, variation of FOS with bench angle-30 m bench height

Bench angle (in degrees)	Factor of safety
20	1.61
25	1.31
26	1.27
27	**1.21**
28	1.18
29	1.13
30	1.11
35	0.97
40	0.83
45	0.75

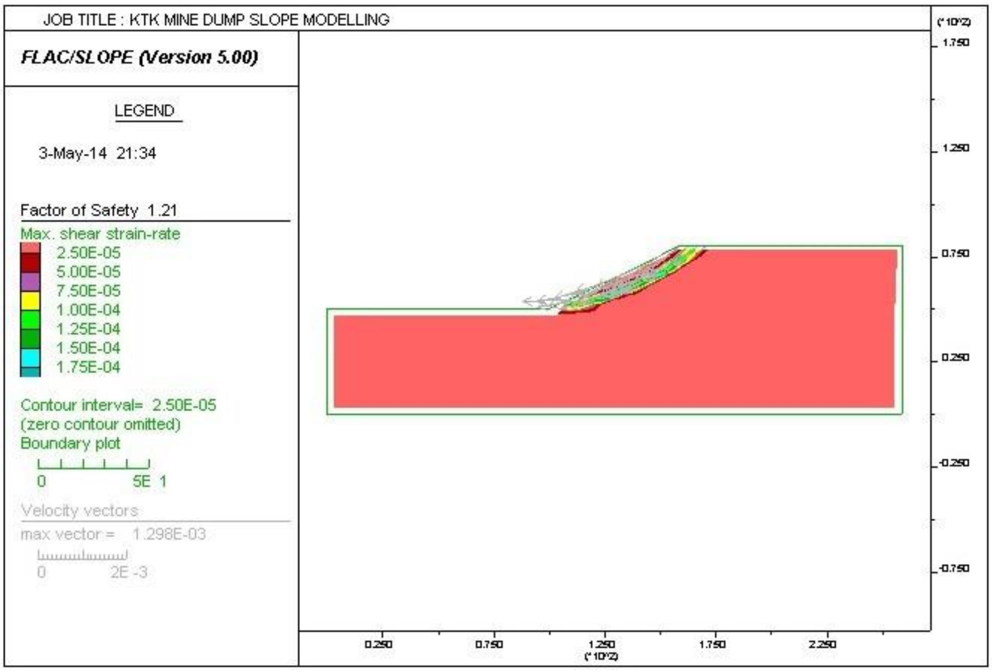

Figure 4.13: FOS for 30 metre OB+15% Fly-ash bench at 27^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 20 metre**

Table 4.18: For OB+15% fly-ash bench, variation of FOS with bench angle-20 m bench height

Bench angle (in degrees)	Factor of safety
20	1.63
25	1.45
26	1.40
27	1.35
28	1.33
29	1.28
30	1.26
35	1.09
40	0.96
45	0.88

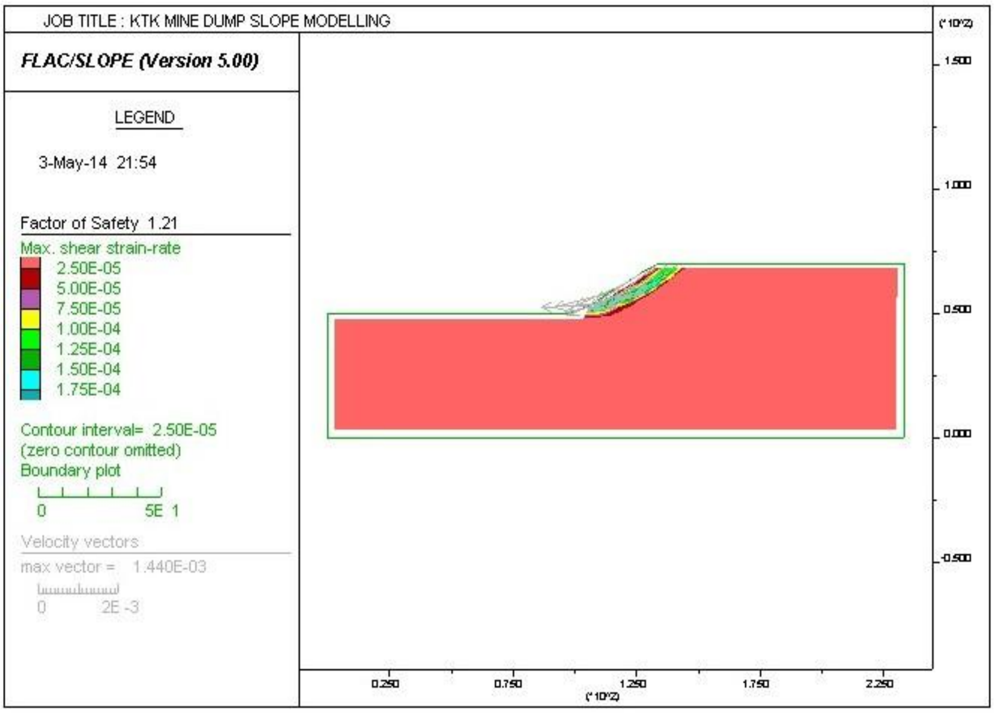

Figure 4.14: FOS for 20 metre OB+15% Fly-ash bench at 31^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 10 metre**

Table 4.19: For OB+15% fly-ash bench, variation of FOS with bench angle-10 m bench height

Bench angle (in degrees)	Factor of safety
20	1.69
25	1.89
26	1.80
27	1.75
28	1.70
29	1.66
30	1.62
35	1.45
40	1.41
45	1.30

Table 4.20: Safe bench angle for OB+15% fly-ash dumps at different bench height

Bench height (in metres)	Maximum Safe bench angle (in degrees)
30	27
20	31
10	Not found within 45^0

4.1.2.3 Condition 3:- The Dumped material is OB+30% fly-ash

- **Height of the deck is fixed at 30 metre**

Table 4.21: For OB+30% fly-ash bench, variation of FOS with bench angle-30 m bench height

Bench angle (in degrees)	Factor of safety
20	1.61
25	1.38
26	1.32
27	1.27
28	**1.24**
29	1.18
30	1.17
35	1.01
40	1.01
45	0.78

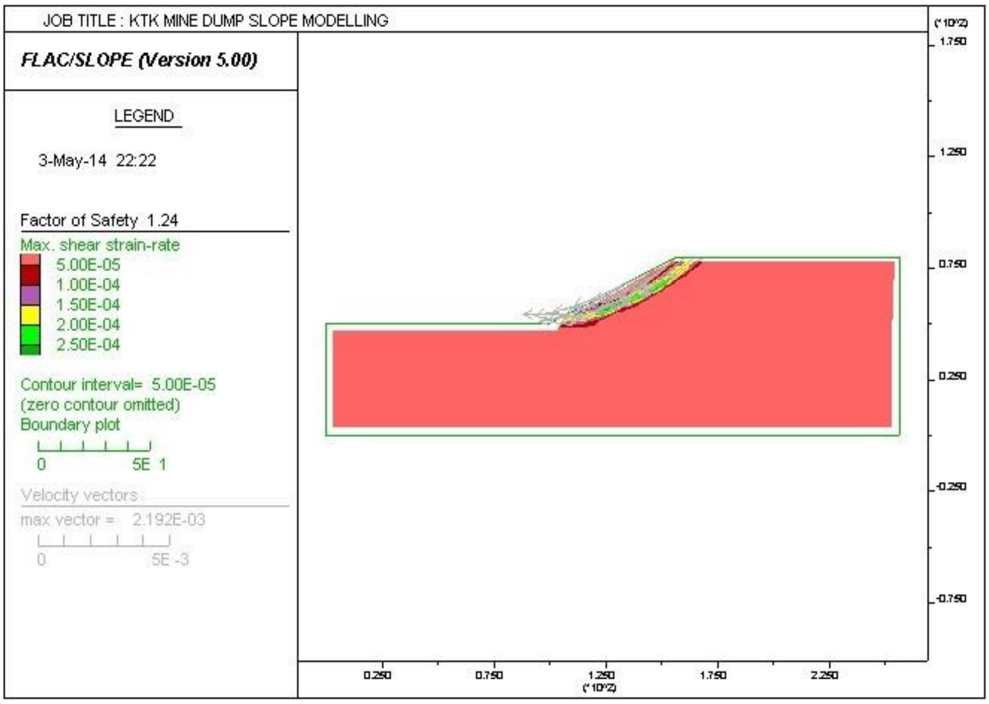

Figure 4.15: FOS for 30 metre OB+30% Fly-ash bench at 28^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 20 metre**

Table 4.22: For OB+30% fly-ash bench, variation of FOS with bench angle-20 m bench height

Bench angle(in degrees)	Factor of safety
20	1.70
25	1.50
26	1.47
27	1.42
28	1.38
29	1.32
30	1.31
35	1.10
40	0.97
45	0.91

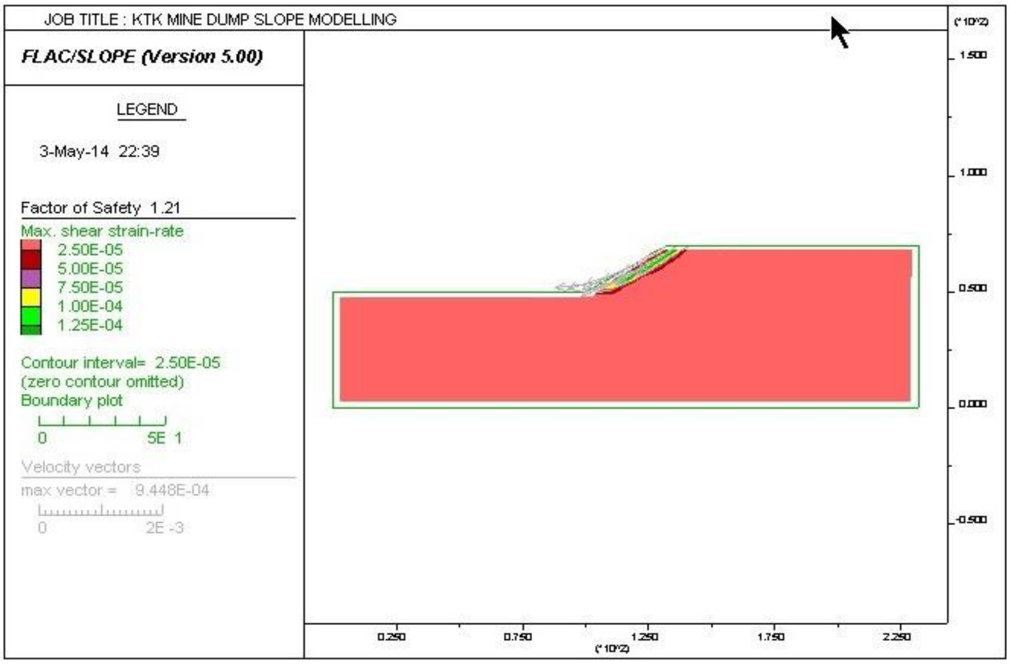

Figure 4.16: FOS for 20 metre OB+30% Fly-ash bench at 32^0 bench angle using FLAC SLOPE

- **Height of the deck is fixed at 10 metre**

Table 4.23: For OB+30% fly-ash bench, variation of FOS with bench angle-10 m bench height

Bench angle (in degrees)	Factor of safety
20	1.75
25	1.93
26	1.89
27	1.82
28	1.80
29	1.73
30	1.68
35	1.50
40	1.46
45	1.33

Table 4.24: Safe bench angle for OB+30% fly-ash dumps at different bench height

Bench height (in metres)	Maximum Safe bench angle (in degrees)
30	28
20	32
10	Not found within 45^0

4.2 MODELLING OF MINE B

4.2.1 FLAC SLOPE

A total of two conditions are assumed namely: Alternate layer OB and OB+25% fly-ash present and an admixture of OB+25% fly-ash present in entire dump. In the first condition I have taken 5 cm layer thickness to simulate the exact condition of mine B. A total of 3 decks is taken with each deck of 30 metre height. Now, in the above 2 conditions, four sub-conditions are applied to see the effect of changing overall slope angle on factor of safety. In the sub-conditions, I have fixed the bench width and varied the bench angle to see the change in overall slope angle and hence factor of safety.

From the previous experiments conducted by Prof. Singam Jayanthu, I have taken the Maximum dry density, Optimum moisture content, Cohesion and Friction angle data for OB as 1.87 g/cc, 11.4%, 41.8 KN/m^2 and 28.5^0 respectively. For OB+25% fly-ash the values are taken as 1.74 g/cc, 12.85%, 89.6 KN/m^2 and 22.9^0 respectively. The wet density of OB material is calculated to be 2.08 g/cc and for OB+25% fly-ash admixture to be 1.96 g/cc. The base of the dumped material is assumed to be of soil-sand uniform coarse material and all the factor of safety calculation is done assuming medium grained material.

4.2.1.1 Condition 1: Alternate layer OB and OB+25% fly-ash present

- **Bench width is fixed at 35 metres**

Table 4.25: Variation of FOS with overall slope angle for Alternate layer OB and OB+25% fly-ash bench at 35 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	20.61	2.05
30	21.72	1.90
32	22.81	1.87
34	23.87	1.82
36	24.90	1.78
38	25.92	1.74
45	29.36	1.57

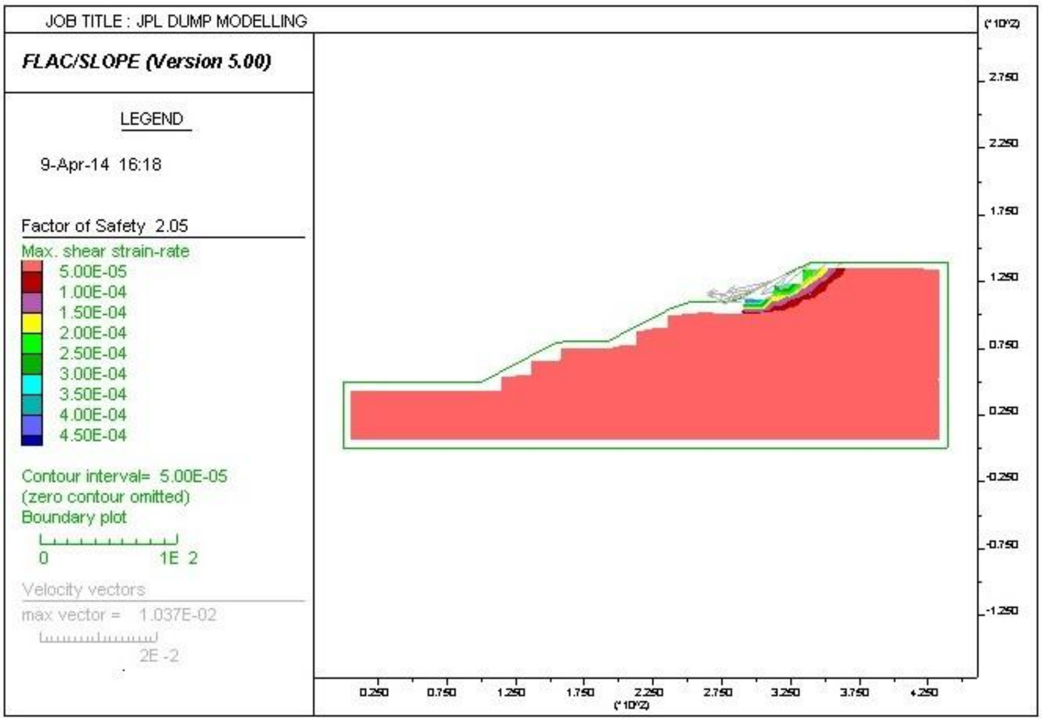

Figure 4.17: FOS for 35 m wide, alternate layer OB and OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 40 metres**

Table 4.26: Variation of FOS with overall slope angle for Alternate layer OB and OB+25% fly-ash bench at 40 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.85	2.06
30	20.88	2.05
32	21.89	1.84
34	22.87	1.83
36	23.82	1.77
38	24.76	1.71
45	27.9	1.55

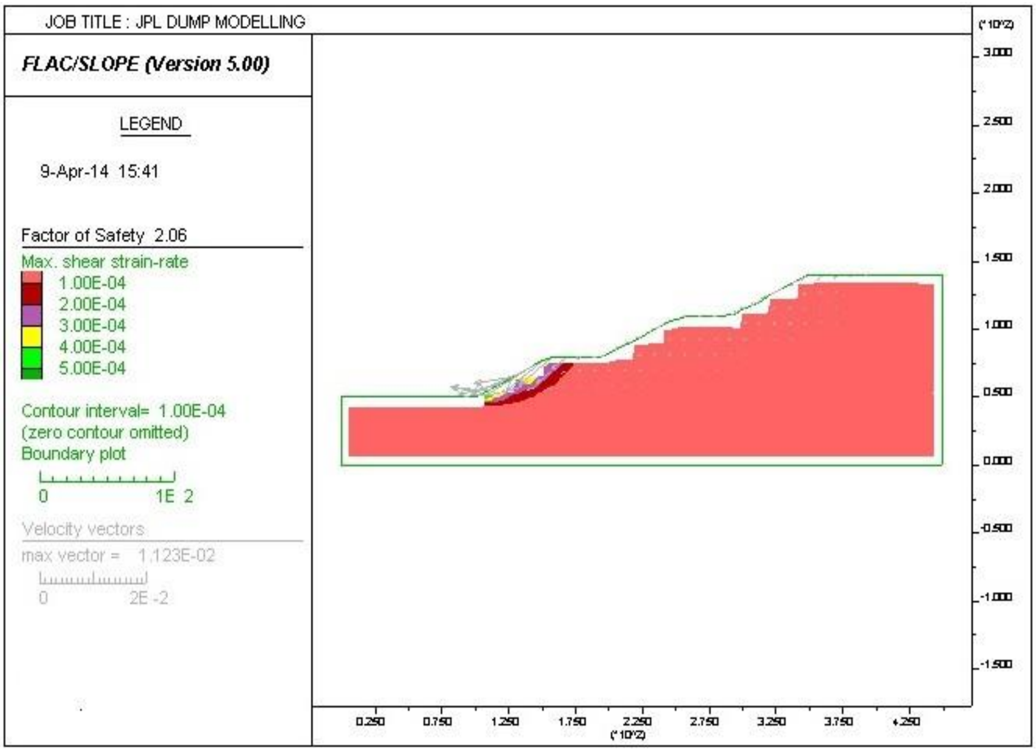

Figure 4.18: FOS for 40 m wide, alternate layer OB and OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 45 metres**

Table 4.27: Variation of FOS with overall slope angle for Alternate layer OB and OB+25% fly-ash bench at 45 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.14	2.06
30	20.10	2.02
32	21.04	1.96
34	21.94	1.83
36	22.82	1.78
38	23.68	1.76
45	26.57	1.64

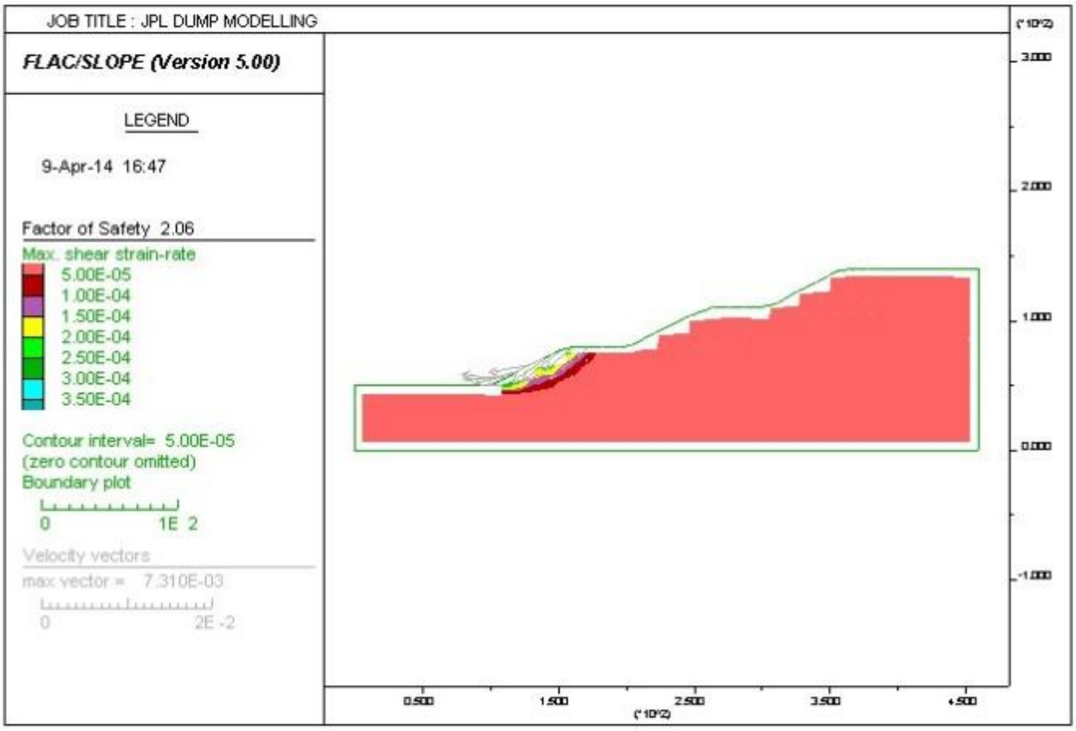

Figure 4.19: FOS for 45 m wide, alternate layer OB and OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 50 metres**

Table 4.28: Variation of FOS with overall slope angle for Alternate layer OB and OB+25% fly-ash bench at 50 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	18.48	2.27
30	19.38	1.97
32	20.24	1.89
34	21.09	1.87
36	21.90	1.72
38	22.70	1.70
45	25.35	1.68

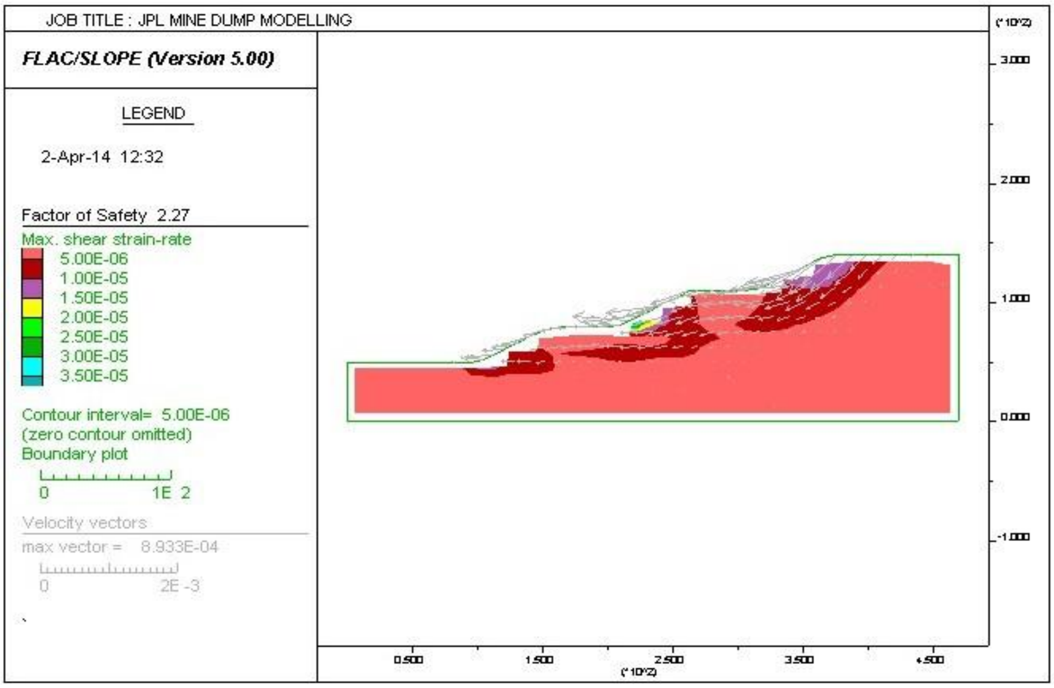

Figure 4.20: FOS for 50 m wide, alternate layer OB and OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

4.2.1.2 Condition 2: Admixture of OB+25% fly-ash in the entire dump

- **Bench width is fixed at 35 metres**

Table 4.29: Variation of FOS with overall slope angle for admixture of OB+25% fly-ash bench at 35 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	20.61	2.71
30	21.72	2.56
32	22.81	2.40
34	23.87	2.35
36	24.90	2.26
38	25.92	2.19
45	29.36	1.98

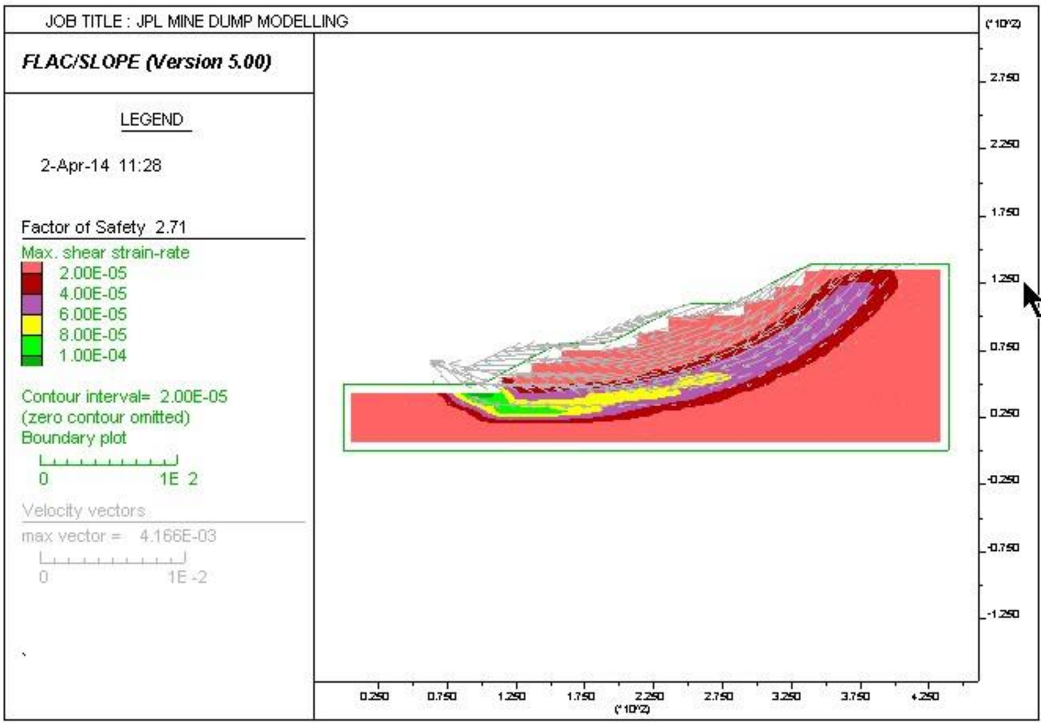

Figure 4.21: FOS for 35 m wide, admixture of OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 40 metres**

Table 4.30: Variation of FOS with overall slope angle for admixture of OB+25% fly-ash bench at 40 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.85	2.81
30	20.88	2.69
32	21.89	2.60
34	22.87	2.51
36	23.82	2.38
38	24.76	2.30
45	27.90	2.10

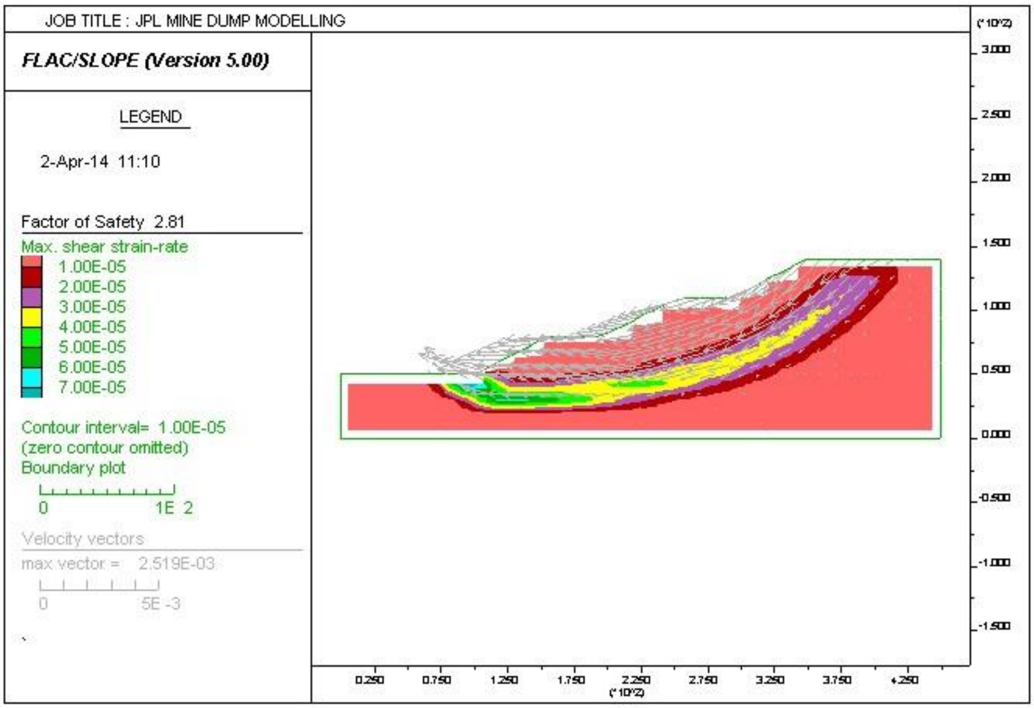

Figure 4.22: FOS for 40 m wide, admixture of OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 45 metres**

Table 4.31: Variation of FOS with overall slope angle for admixture of OB+25% fly-ash bench at 45 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.14	2.93
30	20.10	2.81
32	21.04	2.71
34	21.94	2.61
36	22.82	2.53
38	23.68	2.42
45	26.57	2.21

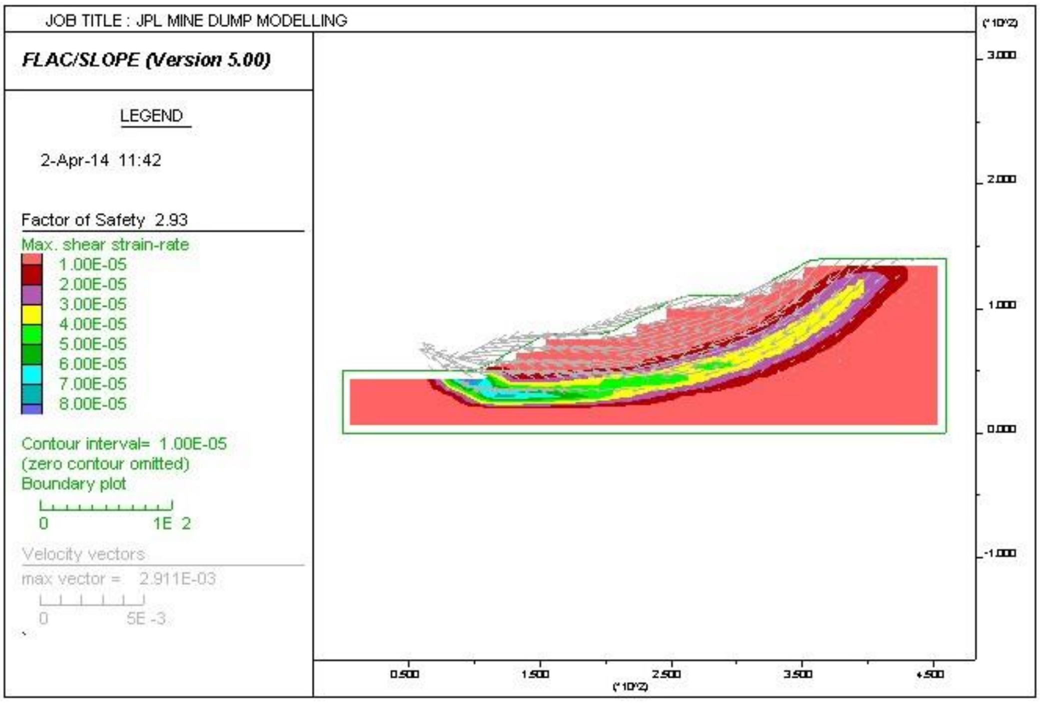

Figure 4.23: FOS for 45 m wide, admixture of OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

- **Bench width is fixed at 50 metres**

Table 4.32: Variation of FOS with overall slope angle for admixture of OB+25% fly-ash bench at 50 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	18.48	2.34
30	19.38	2.26
32	20.24	2.19
34	21.09	2.12
36	21.90	2.06
38	22.70	2.00
45	25.35	1.83

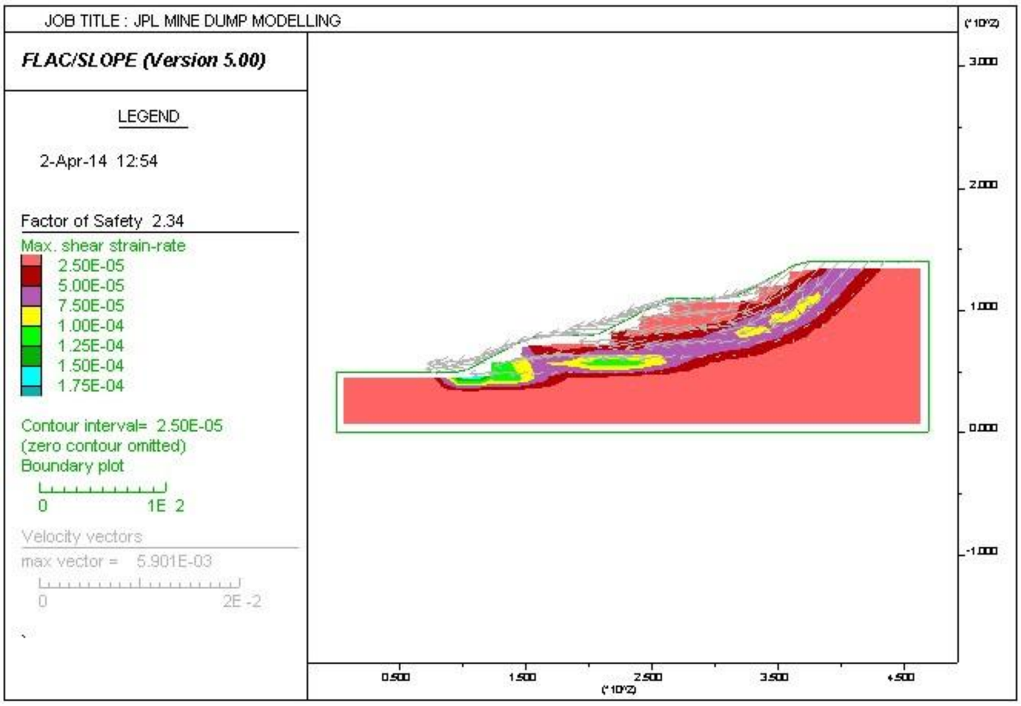

Figure 4.24: FOS for 50 m wide, admixture of OB+25% fly-ash benches, at 28^0 deck angle using FLAC SLOPE

4.2.2 OASYS

In OASYS, I have modelled the above two conditions and for each condition I have taken one sub-condition (bench width fixed at 40 metres). I have taken this sub-condition because it exactly simulates the mine dump condition. All the parameters taken in FLAC SLOPE are kept same. All boundary conditions are also kept same.

4.2.2.1 Condition 1: Alternate layer OB and OB+25% fly-ash present

- **Bench width is fixed at 40 metres**

Table 4.33: Variation of FOS with overall slope angle for Alternate layer OB and OB+25% fly-ash bench at 40 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.85	2.257
30	20.88	2.114
32	21.89	1.995

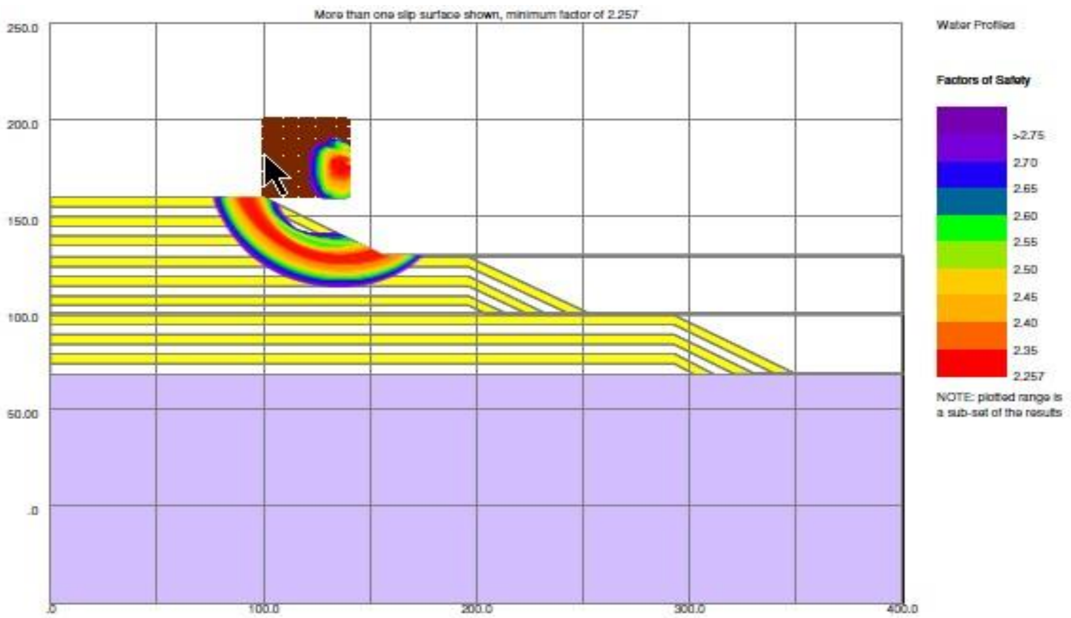

Figure 4.25: FOS for 40 m wide, alternate layer OB and OB+25% fly-ash benches, at 28^0 deck angle using OASYS (minimum FOS is 2.257)

4.1.2.2 Condition 2: Admixture of OB+25% fly-ash in the entire dump

Bench width is fixed at 40 metres

Table 4.34: Variation of FOS with overall slope angle for admixture of OB+25% fly-ash bench at 40 m bench width

Deck angle (in degrees)	Overall slope angle (in degrees)	Factor of safety
28	19.85	2.463
30	20.88	2.356
32	21.89	2.263

Figure 4.26: FOS for 40 m wide, admixture of OB+25% fly-ash benches, at 28^0 deck angle using OASYS (minimum FOS is 2.463)

CHAPTER 5

FIELD EXPERIMENTAL STUDY

Pit 1 and Pit 2 of JPL mine dump (MINE B), were monitored using Total station and monitoring stations. The monitoring stations were installed at 20-30 m intervals and 5 m behind the crest of the dump. Vertical displacement from Nov'12- Nov'13 is presented in the table below

5.1 FIELD MONITORING OF MINE B, PIT 1

Table 5.1: R.L of monitoring stations installed at the dump site with OB and OB+25% fly-ash in alternate layers in pit 1 [4].

Pillar no.	R.L on 16/11/13	Nov'12-Mar'13	Mar'13-Jun'13	Jun'13-Aug'13	Aug'13-Nov'13	Nov'12-Nov'13
AS1	332.433	0	0	0	0	0
AS2	333.528	0	0	0	0	0
AS3	334.311	0	0	-0.002	0	-0.002
AS4	334.744	-0.001	0	-0.002	-0.001	-0.004
AS5	334.840	-0.005	0	-0.003	0	-0.008
AS6	335.064	-0.018	-0.001	0	0	-0.019
AS7	335.036	-0.015	-0.002	0	0	-0.017
AS8	335.010	0	0	0	0	0
AS9	334.197	-0.015	-0.002	-0.003	-0.001	-0.021
AS10	334.805	-0.016	-0.001	0	-0.001	-0.018
AS11	334.854	0	0.001	0	0	0.001
AS12	334.608	0	0	0	0	0
AS13	333.940	0	0	-0.002	-0.001	-0.003
AS14	332.562	0	-0.001	0	0	-0.001
AS15	332.458	0	0	0	0	0
AS16	333.417	0	-0.001	0	0	-0.001
AS17	334.070	-0.001	0	-0.002	0	-0.003
AS18	334.478	0	0	0	0	0
AS19	334.708	0	0	0	0	0
AS20	334.711	0	-0.002	0	0	-0.002
AS21	334.823	0	0	0	0	0
AS22	335.031	-0.002	0	0	0	-0.002
AS23	335.194	-0.003	0	-0.001	0	-0.004

5.2 FIELD MONITORING OF MINE B, PIT 2

Table 5.2: R.L of monitoring stations installed at the dump site with OB and OB+25% fly-ash in alternate layers in pit 2 [4].

Pillar no.	R.L on 16/11/13	Nov'12-Mar'13	Mar'13-Jun'13	Jun'13-Aug'13	Aug'13-Nov'13	Nov'12-Nov'13
KJS1	313.948	0	0	0	0	0
KJS2	313.690	-	-	-	-	-
KJS3	314.158	0	0	0	0	0
KJS4	313.907	-0.02	-0.001	0	0	-0.021
KJS5	314.713	0	0	0	0	0
KJS6	314.393	0	0	0	0	0
KJS7	314.998	0	0	0	0	0
KJS8	315.072	0	-0.001	0	0	-0.001
KJS9	315.121	0	0	-0.002	0	-0.002
KJS10	315.263	0	0	0	0	0
KJS11	315.058	-0.01	0	0	0	-0.01
KJS12	314.748	-0.005	0	0	0	-0.005
KJS13	314.188	0	0	0	0	0
KJS14	313.820	0	-0.001	-0.001	-0.001	-0.003
KJS15	313.833	0	0	0	0	0
KJS16	314.001	0	-0.002	0	0	-0.002
KJS17	314.253	0	0	0	0	0
KJS18	315.473	0	0	0	0	0
KJS19	314.692	-0.001	0	0	0	-0.001
KJS20	314.283	0	0	0	0	0
KJS21	314.412	0	-0.001	0	0	-0.001
KJS22	314.540	0	0	-0.002	-0.001	-0.003
KJS23	314.801	-0.002	0	0	0	-0.002
KJS24	315.347	-0.005	-0.001	0	0	-0.006

CHAPTER 6

OBSERVTION AND ANALYSIS

6.1 ANALYSIS OF MINE A DUMP

6.1.1 Graphical Analysis of the Results Obtained in OASYS Software

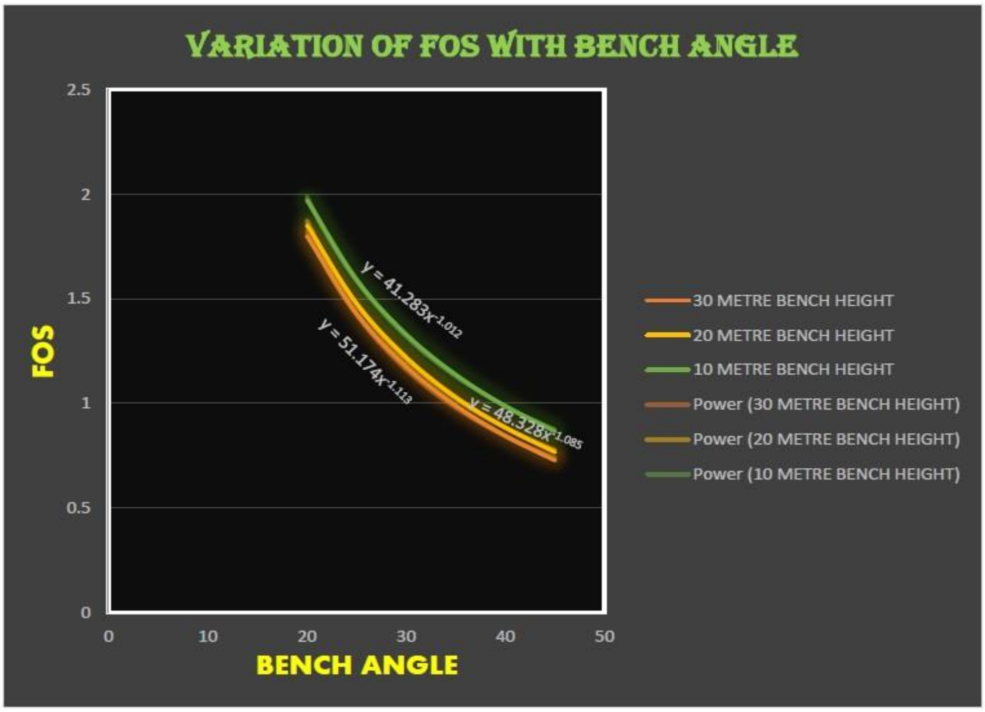

Figure 6.1: Variation of FOS with bench angle for OB dump at different bench height

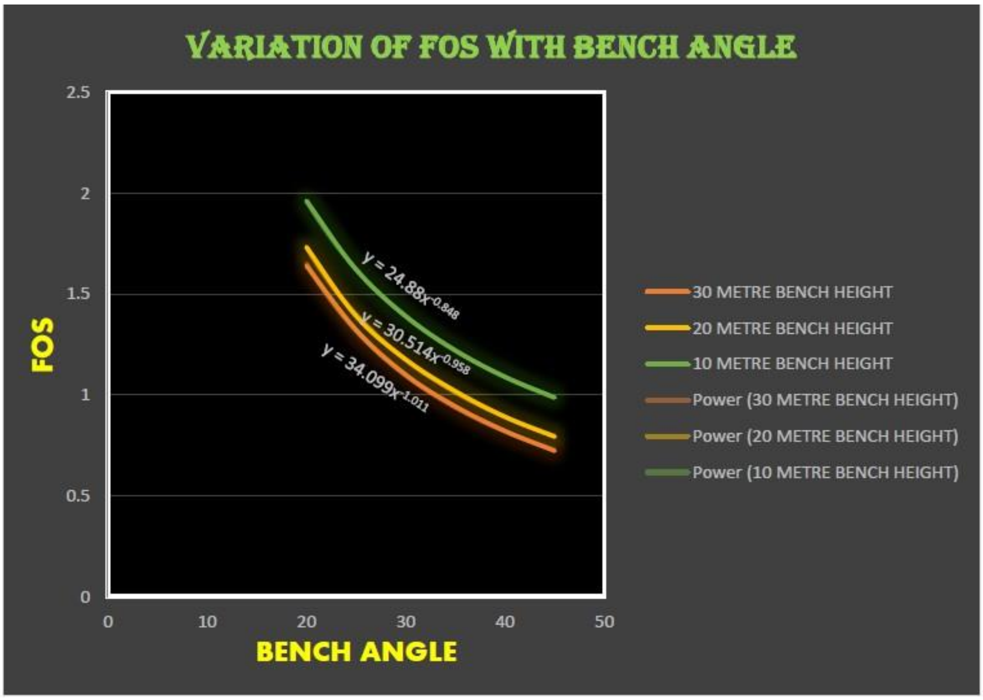

Figure 6.2: Variation of FOS with bench angle for OB+15% fly-ash dump at different bench height

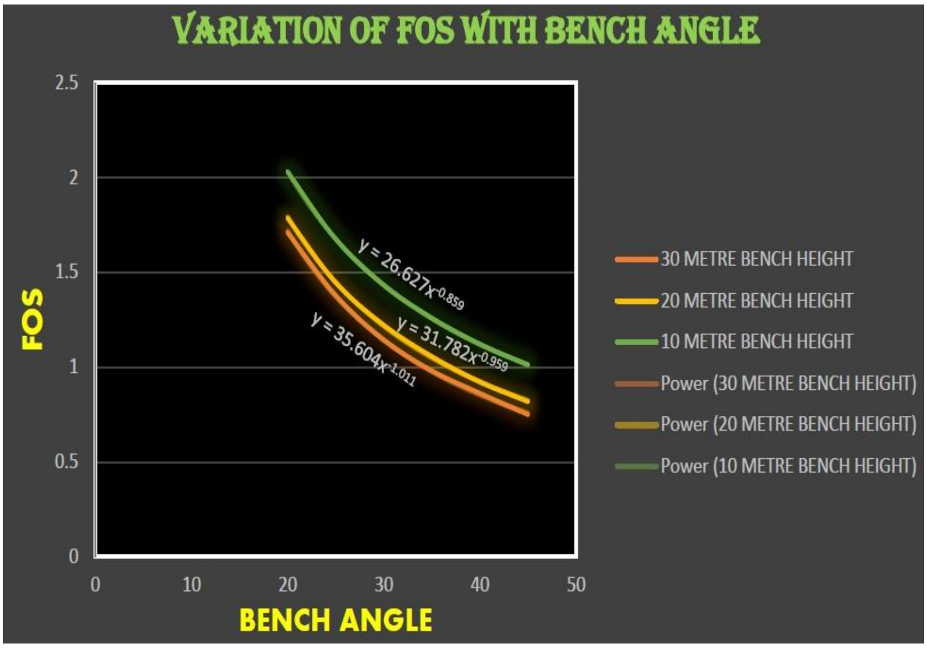

Figure 6.3: Variation of FOS with bench angle for OB+30% fly-ash dump at different bench height

From figure 6.1, 6.2 and 6.3, we can see that for same bench angle lower the bench height, more is the factor of safety and for a particular bench height factor of safety decreases with bench angle. A power trend-line best fits the points. Empirical equations between bench angle (x) and FOS (y) for different bench height is shown in the curves.

In case of OB dump the co-efficient of correlation for 10, 20 and 30 m benches are 0.9993, 0.999 and 0.9987 respectively. Similarly for OB+15% fly-ash dump and OB+30% fly-ash dump, the coefficient of correlation are 1, 0.9998, 0.9997 and 1, 0.9997, 0.9994 respectively. We can see that we are getting a high correlation between FOS and bench angle, so the equations generated can be relied upon to find FOS for other bench angles.

6.1.2 Comparison of the Safe Bench Angle

Table 6.1: Comparing variation of safe bench angle (in degrees), for different bench heights and dump material

Materials	**Bench Height (in metres)**					
	OASYS Software			**FLAC SLOPE Software**		
	10	**20**	**30**	**10**	**20**	**30**
OB	33	30	29	40	31	29
OB+15% Fly-ah	35	29	27	Above 45	31	27
OB+30% Fly-ash	36	30	28	Above 45	32	28

From Table 6.1 we can see that for 30 m bench height, both the software give same result. The general trend is that, with addition of 15% fly-ash the safe bench angle decreases. This might be due to the partial fulfilment of voids. Again with 30% addition of fly-ash the safe bench angle slightly increases. This might be because of complete void fulfilment. In 20 m bench height also the same trend is somewhat repeated. But the interesting case is 10 metre bench height. Here with addition of 15% fly-ash the safe bench angle increases. This might be because of complete fulfilment of void spaces.

6.2 ANALYSIS OF MINE B DUMP

6.2.1 Graphical Analysis of FOS Obtained from Different Dump Construction Method

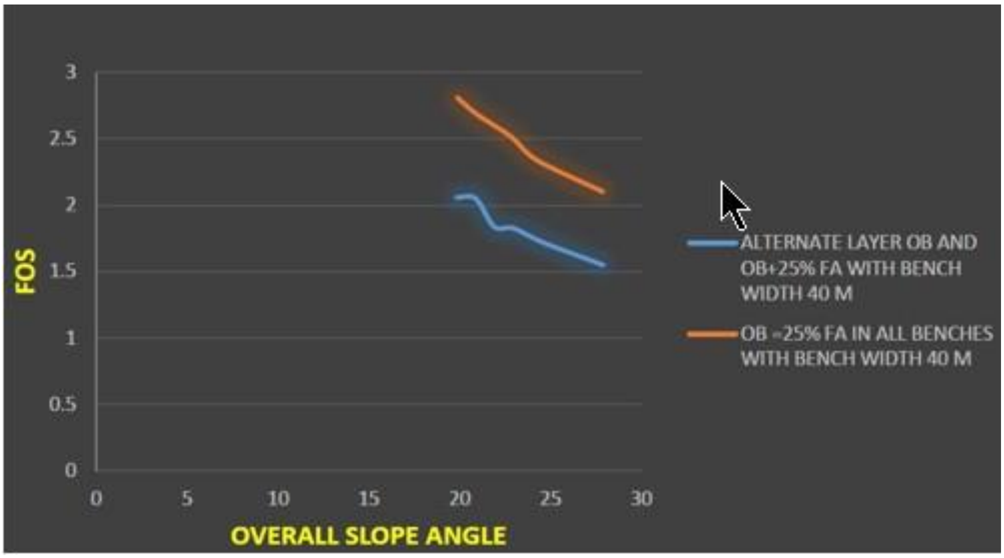

Figure 6.4: Variation of factor of safety with overall slope angle for different dump construction method

We can see from the above graph that, if we construct the overburden with layers then we will obtain a less factor of safety as compared to constructing it with a single material (OB+25% fly-ash). This can be attributed to two reasons:-

- Fly-ash has less unit weight as compared to OB material. So, if we are constructing the dump with only OB+25% fly-ash then the sliding force will reduce. Hence we can obtain a higher factor of safety.
- Fly-ash is much finer than OB materials. So it occupies the void space between OB particles. Hence constructing the dump with only OB+25% fly-ash will give less void ratio and more factor of safety.

The equations obtained for different bench widths in different conditions for OB construction was extrapolated to find the FOS at different overall slope angle. The co-efficient of correlation between FOS and overall slope angle, for constructing the dump with a single mixture

(OB+25% fly-ash) was found good (R^2>0.99) for all bench widths. Hence only this condition was extrapolated below.

Table 6.2: Variation of FOS with Overall slope angle at different bench widths, for same material (OB+25% fly-ash) dump construction

Overall slope angle	Bench widths (in metres)			
	35	**40**	**45**	**50**
19	2.87	2.92	2.96	2.29
21	2,63	2.68	2.71	2.13
23	2.43	2.47	2.51	1.98
25	2.26	2.30	2.33	1.85
27	2.11	2.15	2.18	1.61
29	1.98	1.90	1.93	1.50

6.2.2 Comparison and Analysis of FOS

When dump is constructed layer wise keeping bench width at 40 m, the following comparison between FLAC SLOPE and OASYS FOS is obtained:

Table 6.3: Comparison of FOS at different Overall slope angle

Overall slope angle	FLAC SLOPE FOS	OASYS FOS
19.85	2.06	2.257
20.88	2.05	2.114
21.89	1.84	1.995

- The difference in result might be attributed to the fact that both the software use different analysis techniques as discussed in section 2.7.1.2 and 2.7.2.2.
- Moreover a higher factor of safety is obtained for OASYS software because it assumes the failure surface to be moving in a direction lying in the arc of a circle. But in FLAC

SLOPE any direction of failure can be obtained. Hence a lesser FOS is obtained in case of FLAC SLOPE.

- The grid size in FLAC SLOPE might be another factor. By changing the grid size from medium to fine the results will also change.

6.3 ANALYSIS OF FIELD MONITORING RESULTS

6.3.1 Analysis of Pit 1

- Some stations in pit 1 namely: AS1, AS2, AS8, AS12, AS15, AS19, AS21, doesn’t show any vertical movement. This means they are stable and well compacted. No more investigations is required for this stations.
- Some stations like AS6, AS7, and AS22 show gradual decreasing trend of vertical displacement with time. This means the void spaces are gradually getting filled up and they are attaining stability.
- All other stations show either a decreasing to increasing trend or zero to increasing and then decreasing trend. It means they are not stable and require further monitoring.
- Overall 30.43% of the stations show displacement greater than 3 mm as shown in figure 6.6. They need more focus as they are more unstable. Stations showing less than 3 mm movement are stable.

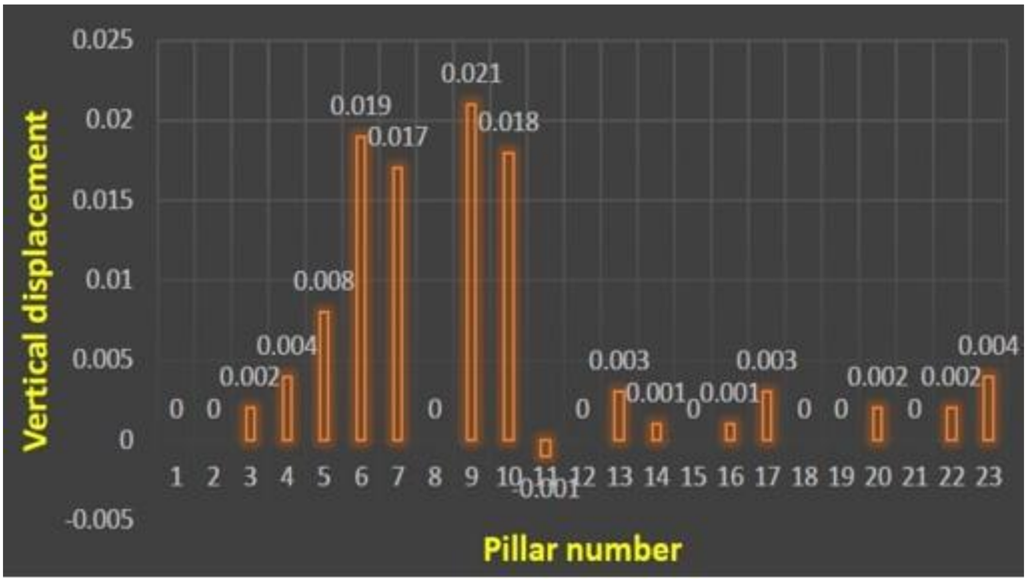

Figure 6.5: Vertical displacements in various pillars of pit1

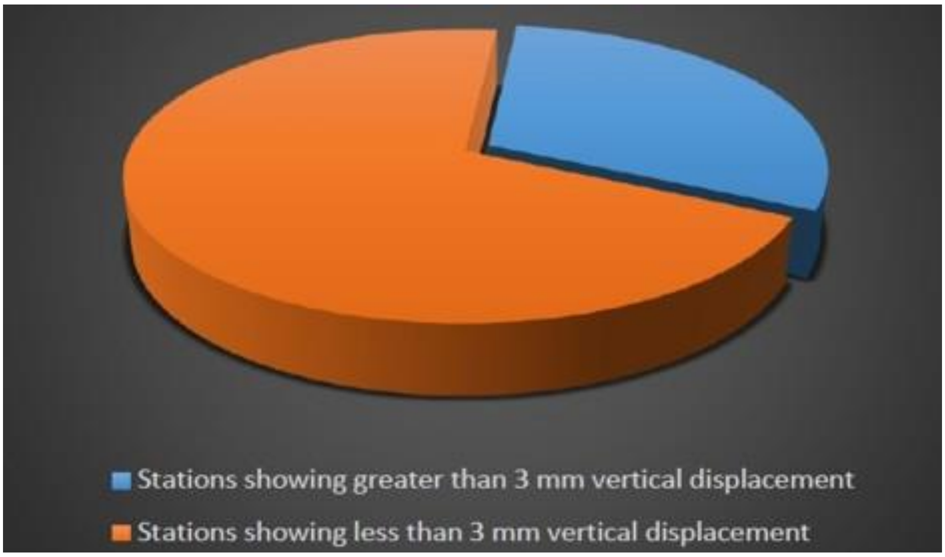

Figure 6.6: Percentage of stations showing less than and more than 3 mm displacement in pit 1

6.3.2 Analysis of pit 2

- Most stations of pit 2 namely: KJS1, KJS3, KJS5, KJS6, KJS7, KJS10, KJS13, KJS15, KJS17, KJS 18 and KJS 20, show zero vertical displacement from the starting. They need not to be studied further. They are well compacted and highly stable.

- Some stations like KJS4, KJS11, KJS12, KJS19, KJS23, and KJS24 show gradual vertical displacement. Interestingly all these stations didn't show any vertical displacement in the quarter Aug'13-Nov'13. It means they have become stable.
- All other stations show haphazard vertical displacement, which indicates a potential chance for failure. They need to be investigated further.
- Overall 12.5% stations only show vertical displacement greater than 3 mm as shown in figure 6.8. But all these 3 stations (KJS4, KJS12, and KJS24) are not showing any vertical displacement in the last two quarters. So, we can say it has become stable, but we need to analyse its trend for another one or two quarters.
- KJS14 and KJS22 need to be investigated more thoroughly as they have showed vertical displacements in the last two quarters. Haphazard vertical displacement in these stations might be because of rain water seepage through the grains.
- Readings in KJS2 station is disturbed due to the movement of machineries.

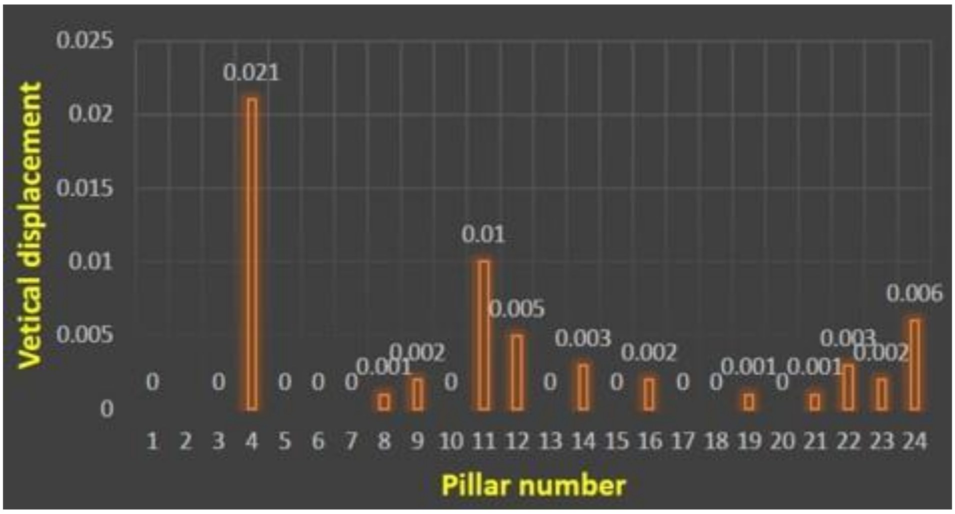

Figure 6.7: Vertical displacements in various pillars of pit2

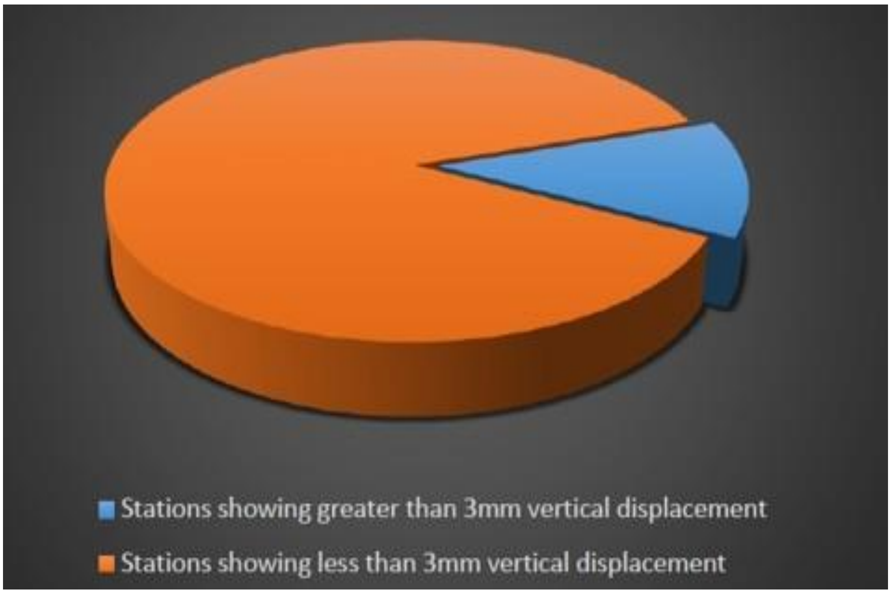

Figure 6.8: Percentage of stations showing less than and more than 3 mm displacement in pit 2

CHAPTER 7

CONCLUSION

CONCLUSION

Based on Numerical modelling for the geo-mining conditions of mine A and B and field monitoring of mine B, the following conclusions are drawn:

1) Factor of safety decreases with increase in deck angle and bench height for all conditions.

2) For mine A, with addition of 15% fly-ash for a 30 m bench, the safe bench angle decreased by 2^0. This may be attributed to the fact that, the void spaces are only partially filled. With addition of 30% fly-ash the safe bench angle increased by 1^0, which may be attributed to filling of void spaces.

3) In contrary, for mine A, the safe bench angle for 10 m bench height increased by 2^0 (in OASYS) with addition of 15% Fly-ash. This may be due to less void spaces available in a 10 m bench height, which can be filled with 15% fly-ash.

4) For the simulated conditions of 30 m bench height, 28^0 deck angle and 40 m bench width of mine B, the FOS indicated through FLAC SLOPE for same material (OB+25% fly-ash) dump construction and layer wise dump construction are respectively 2.81 and 2.06. The difference may be because of reduction in unit weight and filling of void spaces in the former case.

5) From the field monitoring of Mine B dump, it is established that both the pits are stable.

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